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STUDIES OF THE NOCTURNAL RADIATION TO SPACE

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I. HISTORICAL SURVEY

The first observations relating to the problem of the earth's radiation to space are due to Wilson,[1] Wells,[2] Six,[3] Pouillet,[4] and Melloni,[5] the observations falling between the years 1780 and 1850. These observers have investigated the nocturnal cooling of bodies exposed to the sky, a cooling that evidently is not only due to radiation but is also influenced by conduction and convection of heat through the atmosphere. Melloni draws the conclusion from his experiments that this cooling is for the most part due to the radiation of heat to space.

In the year 1885, J. Maurer[6] published a paper dealing with the cooling and radiation of the atmosphere during the night. From thermometrical observations of the atmosphere's cooling, Maurer deduces a value $\sigma = 0.007 \cdot 10^{-4}$ (cm³ min.) for the radiation coefficient of the air and from this a value for the radiation of the whole atmosphere: $0.39 \frac{\text{cal.}}{\text{cm}^2 \text{ min.}}$ at 0°. This value is obtained

[1] *Edinburgh Phil. Trans.*, **1**, 153.

[2] *Ann. de chimie et de physique*, **3**, Ger. Vol. **5**.

[3] Six, *Posthumous Works*. Canterbury, 1794.

[4] Pouillet, *Eléments de physique*, 1844.

[5] *Annales de chimie et de physique*, 1848.

[6] *Met. Zeitschrift*, 1886.

on the assumption that the atmosphere is homogeneous, having a height of $8 \cdot 10^5$ cm and by application of the formula

$$R = \frac{S}{a}(1 - e^{-ax}) ,$$

where a is the absorption coefficient deduced from the radiation coefficient by the application of Kirchhoff's law. I will make some remarks on the theoretical foundation of Maurer's value for the atmospheric radiation in the theoretical part of this paper. In the year 1887, Maurer[1] made measurements on the nocturnal radiation to space from a blackened body and obtained a value of 0.13 $\frac{\text{cal.}}{\text{cm}^2 \text{ min.}}$ for this radiation (June; temp. 15°–18°).

Pernter[2] has measured the nocturnal radiation at Sonnblick (alt. 3095 m) and simultaneously at Rauris (alt. 900 m) and obtained the values 0.201 and 0.151 respectively. Pernter made his observations with an actinometer of the Violle type.

In the year 1897, Homén[3] published an important paper bearing the title, *Der tägliche Wärmeumsatz im Boden und die Wärmestrahlung zwischen Himmel und Erde*. He observed the radiation with an Ångström actinometer, constructed for measuring the insolation but here modified for the purpose of measuring the radiation from earth (irradiation). Homén draws from his observations on the radiation between earth and space the following conclusions:

1. If the sky is clear, there will always be a positive radiation from earth to space, even in the middle of the day.

2. If the sky is cloudy, there will always in the daytime be a radiation from sky to earth.

3. In the night-time the radiation for clear as well as for cloudy sky always has the direction, from earth to sky. Homén made also some measurements on the radiation to different parts of the sky and found that this radiation decreases rapidly when the zenith

[1] *Sitzungsber. d. Berl. Akad.*, 1887.

[2] *Sitzungsber. d. Wiener Akad.*, **47**, 1562, 1888.

[3] Homén, *Der tägliche Wärmeumsatz*, etc. Leipzig, 1897.

angle approaches the value of 90°. His values on the nocturnal radiation for clear sky vary between 0.13 and 0.22 $\frac{\text{cal.}}{\text{cm}^2 \text{ min.}}$.

Exner[1] (1903) made observations on the radiation to space at Sonnblick (alt. 3106 m) and used for this purpose a modified compensation pyrheliometer of K. Ångström's type. The radiation was measured for a limited part of the sky and a correction applied with regard to the distribution of radiation to the different zones found by Homén. Exner found a mean value for the radiation of 0.21 and in agreement with former investigations of Maurer and Homén a relatively constant value for the radiation during the night. He observed a slight maximum in the radiation, one to two hours before sunrise.

In the year 1905, K. Ångström[2] published a description of a new instrument for determining the nocturnal radiation to space. This instrument is founded upon the principle of electric compensation, and as it has been used in the work here published, I will in the following give a short description with some remarks on the advantages and sources of error in the use of this instrument. K. Ångström found a radiation varying between 0.13 and 0.18 for clear sky, the observations being made at Upsala between May 22 and November 7, 1904.

The latest contribution to the question we are dealing with, which I have been able to find, is a paper in *Nuovo Cimento* by A. Lo Surdo.[3] Lo Surdo gives a critical survey of the methods that have been used and discusses some observations of his own, made at Naples in September 1908 with the Ångström nocturnal compensation instrument. Contrary to Homén, he finds even when the sky is clear a positive radiation from sky to earth in the daytime. He observes the variation in the radiation during a clear and specially favorable night and finds a pronounced maximum about two hours before sunrise. Such a maximum had already been observed by Exner on the top of Sonnblick under different

[1] *Met. Zeitschrift* (1903), p. 409.

[2] *Nova Acta Reg. Soc. Scient. Upsal.*, Ser. IV, Vol. 1, No. 2.

[3] *Nuovo Cimento*, 1908.

atmospheric conditions. The following table gives a condensed survey of the results obtained by different observers:

Observer	Date	Place	Temperature	Height	Mean Value
Maurer	June 13–18, 1887	Zürich	15°–18°	500	0.128
Pernter	Feb. 29, 1888	Sonnblick	8°	3095	.201
Pernter	Feb. 29, 1888	Rauris	.....	900	.151
Homén	Aug. 1896	Lojosee	.....	....	.17
Exner	1902	Sonnblick	.....	3106	.19
Exner	July 1, 1902	Sonnblick	.....	3106	.268 (max.)
K. Ångström	May–Nov. 1904	Upsala	0°–10°	200	.155
Lo Surdo	Sept. 5–6, 1908	Naples	20°–30°	30	.182
A. Ångström	July 10–Sept. 10, 1912	Algeria	20°	1160	0.174

The problem of the radiation from earth to space is comparable in importance to the insolation problem for the knowledge of the climatic conditions at a certain place. While the insolation problem has been subjected to a very thorough study, so that we know relatively well the dependence of the insolation on different atmospheric conditions, this cannot be said of the irradiation, of whose dependence on other meteorological conditions we are able to draw very few conclusions from the more sporadic observations made.

What seems to be wanted here are continuous and systematic investigations made simultaneously at different places, the observations so made put in connection with the *height above sea-level, the temperature of the earth and the air, and the composition of the air in regard to water-vapor, ozone, and other constituents.*

The observations here published, made at Bassour, Algeria, at a height of 1160 m, may be regarded as a preliminary contribution to the complicated question of the influence of the constitution of the air on the radiation to space.

That it has been possible to draw some more general conclusions in spite of the short time (July 10–September 10), under which these observations have been carried out, may be due largely to the excellent atmospheric conditions, which permitted me to make observations almost every night under clear sky.

In this first paper I will give an account of some measurements showing *the influence of the water-vapor on the nocturnal radiation;*

in a following paper some observations at different heights and for different zenith angles will be communicated.

To the Smithsonian Institution, which has favored my investigations through a grant from the Hodgkins Fund, and to Mr. C. G. Abbot, director of the Astrophysical Observatory at Washington, in whose solar expedition I have had the honor to take part, and whose experienced counsels have been of great value to this work, I wish to express my most sincere thanks.

II. THEORETICAL CONSIDERATIONS

I shall in the following use the term "effective radiation" for the radiation determined by the loss of heat through radiation from unit area of black surface during one minute. In the case of the nocturnal radiation this effective radiation must be regarded as a sum of several terms: (1) the radiation from the surface to space (E_c), for a black body determined by Stefan's radiation law; (2) the radiation from the atmosphere to the surface (E_a), to which comes the sum of the radiations from planetary bodies (E_s), a radiation source that by Poisson is indicated by the term "sidereal heat." If I is the effective radiation we shall evidently have:

$$I = E_c - E_a - E_s .$$

For the special case where the temperature of the surface is constant and the same is assumed to be the case for the sidereal radiation, we can write

$$I = K - E_a ,$$

where K is a constant. Under these circumstances the variations in the effective radiation are dependent on the atmosphere's radiation only, and the problem is identical with the problem of the radiation from a gaseous body that here is a mixture of several different components.

As is well known from thorough investigations, a gaseous body has no continuous spectrum, but is characterized by a selective radiation, the radiation being relatively strong at certain points of the spectrum and often inappreciable in points lying between. The law for the distribution of energy is generally very complicated

and different for different gases. The intensity is further dependent upon the thickness, density, and temperature of the radiating layer.

Suppose that we consider the intensity of the radiation for a special wave-length λ from a uniform gaseous layer of the thickness R and the temperature T toward a little elementary surface $d\tau$. We shall, to begin with, consider only the radiation that comes in from an elementary radiation cone, perpendicular to $d\tau$, which at unit distance from $d\tau$ has a cross-section equal to $d\Omega$. One can easily deduce:

$$I_\lambda = \int_0^R \epsilon_\lambda e^{-ar} dr d\Omega d\tau = \epsilon_\lambda d\Omega d\tau \int_0^R e^{-a_\lambda r} dr ,$$

which gives

$$I_\lambda = \frac{\epsilon_\lambda}{a_\lambda} d\Omega d\tau (1 - e^{-a_\lambda R}) , \tag{1}$$

where ϵ_λ is the emission coefficient and a_λ the absorption coefficient for the wave-length λ.
Evidently:

$$\lim_{R=\infty} I_\lambda = \frac{\epsilon_\lambda}{a_\lambda} d\Omega d\tau = E_\lambda d\Omega d\tau , \tag{2}$$

where E_λ is the radiation from a black body for the wave-length λ. It follows from this that in all cases where one can assume a_λ independent of the temperature, ϵ_λ must be the same function of the temperature as E_λ multiplied by a constant, that is:

$$\epsilon_\lambda = C\lambda^{-5} \frac{1}{e^{\frac{c_1}{\lambda T}} - 1} .$$

If now the gas has many selective radiation bands, we may write instead of (1):

$$I = \sum \frac{\epsilon_\lambda}{a_\lambda} (1 - e^{-a_\lambda R}) d\Omega d\tau . \tag{3}$$

If R is taken so great that the product $a_\lambda R$ has a very great value for all wave-lengths, the expression (3) will become

$$\lim_{a_\lambda R = \infty} \Sigma E_\lambda = \rho T^4 , \tag{4}$$

which is Stefan's radiation law for a black body.

If $a_\lambda R$ cannot be regarded as infinitely great for all wave-lengths, the radiation I will be a more complicated function of T, expressed through the general expression (3). The less the difference is between the radiation from the gas and the radiation from a black body at the same temperature, so much more accurately will the formula (4) express the relation between radiation and temperature.

Dr. Trabert[1] draws from his observations on the nocturnal cooling of the atmosphere the conclusion that the radiation from unit mass of air is simply proportional to the absolute temperature. If this should be true, it can be explained only through a variation of a_λ with the temperature. Later Paschen[2] and Very[3] have measured in the laboratory the radiation from air layers at different temperatures and found a much more rapid increase with rising temperature.

The relation

$$I = \sum \frac{\epsilon_\lambda}{a_\lambda} (1 - e^{-a_\lambda R}) d\Omega$$

represents the general expression for the radiation within the radiation cone $d\Omega$ perpendicular to the unit of surface. Maurer,[4] in his calculation of the atmospheric radiation, starts with the more simple expression:

$$I = \frac{\epsilon}{a} (1 - e^{-aR}),$$

where he puts R equal to the height of the reduced atmosphere and a equal to the absorption coefficient for unit volume. This is evidently an approximation that is open to criticism and must give a value of the atmospheric radiation that is too great. In the first place, it is not permissible to regard R as the height of the reduced atmosphere, and this for two reasons: first, because the radiation depends chiefly upon the existence of water-vapor and carbondioxide in the atmosphere, whose density decreases rapidly with the altitude; and secondly, because we here have to deal with a radiation that comes in from all sides, R being variable with

[1] *Denkschriften der Wien Akad.*, **59**.

[2] *Wied. Ann.*, **50**, 1893.

[3] Very, *Atmospheric Radiation*. Washington, 1900.

[4] *Loc. cit.*

the zenith angle. But even if we assign to R a mean value with regard to these circumstances, Maurer's formula will be true only for the case of one single emission band and is, for more complicated cases, incapable of giving an idea of the real conditions.

If, with Maurer, we regard the atmosphere as homogeneous and of uniform temperature, having a certain height h, we must, considering that R is a function of the zenith angle, write (1) in the following form:

$$I_\lambda = -\frac{\epsilon_\lambda}{a_\lambda}\int d\Omega\left(1-e^{-a_\lambda\frac{h}{\cos\phi}}\right)\cos\phi\,,$$

where the integration shall be taken over the hemisphere representing the space. Now we have:

$$d\Omega = d\phi d\psi\,\sin\phi\,,$$

and therefore:

$$I_\lambda = -\frac{\epsilon_\lambda}{a_\lambda}\int_0^{2\pi} d\psi \int_0^{\frac{\pi}{2}}\left(1-e^{-a_\lambda\frac{h}{\cos\phi}}\right)\sin\phi\cos\phi d\phi\,.$$

This expression can easily be transformed to

$$I_\lambda = \frac{\epsilon_\lambda}{a_\lambda}\left[\pi-\rho^2\int_\rho^\infty \frac{e^{-x}}{x^3}dx\int_0^{2\pi} d\psi\right],$$

where $\rho = a_\lambda h$. As $h \doteq 0$, this expression approaches zero, when $h \doteq \infty$, I_λ approaches the value $\pi\frac{\epsilon_\lambda}{a_\lambda}$ which is equal to the radiation of a black body at the same temperature. We have in fact:

$$\lim_{\rho=\infty}\rho^2\int_\rho^\infty \frac{e^{-x}}{x^3}dx = \lim_{\rho=\infty}\frac{\frac{e^{-\rho}}{\rho^3}}{\frac{1}{2}\cdot\frac{1}{\rho^3}} = \lim_{\rho=\infty}\frac{e^{-\rho}}{2} = 0\,,$$

and in the same way:

$$\lim_{\rho=0}\rho^2\int_\rho^\infty \frac{e^{-x}}{x^3}dx = \tfrac{1}{2}\,.$$

I have found, as will be seen from the experimental results, that the influence of the water-vapor pressure (p) on the atmospheric radiation at constant temperature can, between certain limits of p, be expressed by a formula:

$$E_a = K - Ce^{-\gamma p},$$

where K, C, and γ are constants.

This relation can be deduced from (3) if we make certain assumptions in regard to the absorption of the gaseous layer. If we collect all terms in the expression (3) for which R is so great that a further increase in R will alter the radiation for the considered wave-length only by a negligible quantity, and for the other terms make the approximation:

$$\Sigma_\epsilon^{-a_\lambda R} = e^{-a_m R_m},$$

we may write the radiation formula in the form:

$$E_a = K - Ce^{-a_m R_m},$$

where R_m may be taken, not as the height of the considered homogeneous atmosphere, but as a mean value in regard to the radiation from all sides. Under the assumption that only the water-vapor pressure is varying and that the effect of the radiation of other atmospheric constituents as carbondioxide, ozone, etc., is included in the constant K, we may put R proportional to the water-vapor pressure at the earth's surface.[1] We arrive in this way at the above formula:

$$E_a = K - Ce^{-\gamma p}.$$

For the effective radiation to space this gives:

$$I = K_1 + Ce^{-\gamma p}.$$

This expression, founded as it is on assumptions that are approximately true only within certain limits ($p_1 < p < p_2$), is, however, in its general form in good agreement with the observations that I have made and that are described in a later part of this paper. That the formula in its relatively simple form can be applied to the atmospheric radiation as a function of the water-vapor pressure has its explanation in the form of the radiation-curve of water-vapor, as derived from the investigations of Rubens, Aschkinass,

[1] Hann, *Meteorologie*, pp. 224–226.

and others on its absorption.[1] It may be seen from these observations that the radiation from the atmosphere, probably for all wave-lengths excluding those between the limits 8 μ and 11 μ, is almost like that of a black body. This circumstance explains why the radiation may be treated as if the variations were due to one emission band only, the radiation between 8 μ and 11 μ being the only part which is dependent on the thickness of the radiating layer (for $R > R_0$). I may from this elementary theoretical consideration pass to a description of the observations and the apparatus used.

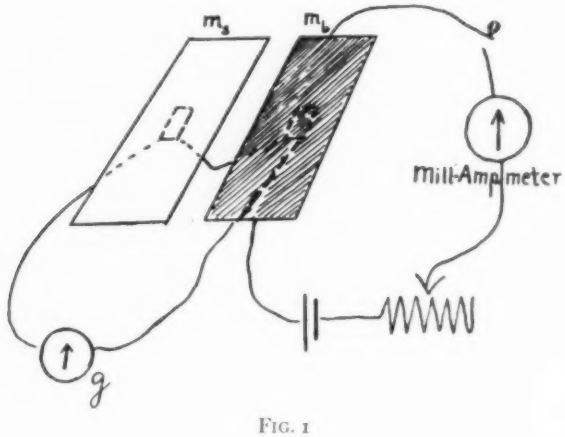

FIG. 1

III. INSTRUMENTS

I used for the following observations two nocturnal compensation instruments of the type described by K. Ångström[2] in a paper in 1905. Without going into details for which I refer to the original paper, it may be advantageous to give here a short description of the instrument.

Founded on the same principle of electric compensation used in the Ångström pyrheliometer, the instrument has the general form indicated in Fig. 1. M_S and M_C are two thin metal strips, of which one is blackened, the other bright. On the backs of the

[1] See also Very, *Atmospheric Radiation*, p. 122.

[2] *Nova Acta Reg. Soc. Scient. Upsal.*, Ser. IV, Vol. 1, No. 2.

metal strips are fastened the two contact points of a thermo-junction, connected with a sensitive galvanometer *g*. If the strips are shadowed by a screen of uniform temperature, the thermo-junctions have approximately the same temperature and we can read a certain zero position on the galvanometer *g*. If the screen is removed and the strips are exposed to the sky, a radiation will take place, which is greater for the black strip than for the bright one, and there will be a deflection on the galvanometer due to the temperature difference between the two strips. In order to regain the zero position of the galvanometer, we may produce the heat lost through radiation by sending an electric current through the black strip. Theoretical considerations, as well as experiments made, show that the radiation is proportional to the square of the current used, that is,

$$I = ki^2,$$

where k is a constant depending upon the dimensions, resistances, and radiating power of the strips. As the radiating power of the strips is difficult to compute, the constant k is determined from experiment with a known radiation. The strips are exposed to radiate to a half-sphere of known temperature T, and the constant is determined by the relation:

$$ki^2 = \sigma(T^4 - T_1^4).$$

The advantage of this construction over the form used, for instance by Exner and Homén, where the effect of conduction and convection also are eliminated, lies in the possibility of measuring the radiation to the whole sky and not only a limited part, which is the case when one of the strips must be shadowed. It must always be regarded as a dangerous approximation to calculate the radiation to the whole sky from the radiation to a limited part, assuming a certain standard distribution of radiation.

On the other hand, the value k here is dependent on the accuracy with which the radiation constant σ is determined. Further, since the emissive power of the strips, which is different for different wave-lengths, enters into the constant k, this constant can be applied only for cases where the radiation is approximately of the same wave-length as in the experiment from which k is

computed. In the night-time, this may be considered the case. But the instrument cannot without further arrangement be used for determining the radiation during the day, where the diffused radiation from the sky of short wave-length enters as an important factor.

The constants of my instruments, made by G. Rose, Upsala, were determined at the Physical Institute at Upsala. In order that all the instruments that are sent out may have constants founded on the same value of σ, Kurlbaum's value has been used. In my case, where the variations of the radiation are of the greatest interest, the absolute value of σ is not of such great importance. It may, however, be remarked that since the values for σ, obtained by later investigators, are somewhat larger than Kurlbaum's value, the observations here given are probably too small.

IV. OBSERVATIONS

The observations given in this part were made at Bassour, Algeria, July 10–September 10, 1912, at a height of 1160 m above sea-level.

In Table I are given the effective radiation R, the date, the time of day, the humidity, the barometric pressure B, and the temperature t. The temperature fall between the time of radiation observation in the evening and the time of sunrise is indicated by Δt.

The observations of Table I are now put together in Table II in such a way that the mean value of the determinations, when the pressure of the water-vapor falls between two certain limits indicated in the table, is calculated (R_m): these mean values are plotted in a curve, Fig. 2, which gives the probable relation between water-vapor pressure and radiation. Tables I and II show that the temperature of the radiating surface has been almost constant for the different series and ought not, therefore, to have had any influence upon the variation in the magnitude of the radiation.

The value of a single observation often deviates from the supposed curve by several per cent. This should not astonish us.

The observations of Abbot and Fowle[1] show that the amount of water-vapor contained in the air can be only roughly estimated from the water-vapor pressure at the earth's surface. Since the

TABLE I

Date	Time	*B*	Temperature	Δt	p	*R*
July 10	7^h40^m	664.4	19.1	...	3.86	0.191
11	7 40	663.6	24.1	...	9.42	.156
12	7 45	662.9	25.4	...	6.60	.171
18	8 30	663.1	20.1	1.8	9.32	.166
19	8 10	662.6	23.3	6.3	8.54	.163
20	8 0	661.9	21.5	6.4	7.08	.166
22	9 30	664.0	17.2	0.6	5.66	.211
23	9 35	663.5	20.0	5.6	7.80	.169
24	8 25	.....	19.5	5.7	8.36	.159
25	8 35	664.9	18.8	−0.5	8.25	.138
29	8 35	665.1	18.0	1.8	9.16	.139
30	10 25	666.7	21.0	3.4	7.14	.187
31	8 35	664.7	22.6	...	4.14	.169
Aug. 1	9 45	662.3	23.8	4.2	4.40	.201
2	8 55	662.9	20.3	2.4	7.54	.171
3	9 05	.....	24.2	...	8.96	.173
4	8 50	663.5	21.2	3.2	6.60	.175
5	7 55	663.2	21.4	3.7	9.88	.162
6	8 50	.....	23.6	3.3	5.89	.173
10	8 50	665.7	25.0	3.3	9.98	.178
11	8 20	666.9	22.8	2.7	10.20	.158
13	9 0	662.7	19.5	1.5	8.86	.171
14	10 0	662.6	18.6	0.0	11.90	.147
15	8 30	665.4	20.6	−1.4	8.61	.179
20	10 10	667.7	18.9	1.7	13.24	.145
21	8 0	669.8	20.8	4.6	6.45	.201
22	8 40	667.9	17.9	2.7	7.44	.173
23	9 0	665.7	20.8	0.5	3.84	.192
24	8 45	663.4	22.0	3.2	5.46	.175
26	8 45	.....	21.5	...	3.80	.217
27	9 5	.....	21.5	...	8.48	.188
29	8 50	665.1	24.4	...	8.36	.190
30	9 15	665.6	20.3	4.4	7.10	.157
Sept. 3	8 35	664.3	13.8	4.2	10.40	.138
4	8 5	666.7	11.1	...	4.98	.169
5	9 50	664.0	20.8	2.1	4.57	.205
6	9 30	661.5	20.0	2.4	3.99	.220
8	9 0	666.7	15.7	−1.0	6.80	0.177

mechanical conditions of the atmosphere are complicated on account of many disturbances, we cannot expect a general rule without considerable deviations. As a result of interest, it may here be mentioned that my comparison of the radiation measure-

[1] *Annals of the Astrophysical Observatory of the Smithsonian Institution*, **2**, 131, 1908.

ments with regard to the corresponding transmission power of the sky, for visible rays, as given by pyrheliometer measurements with colored screen, has shown me that the influence of the "haziness" upon the nocturnal radiation is negligible in comparison with

TABLE II

p	3.50–4.50			4.50–5.50			5.50–6.50		
	t	p	R	t	p	R	t	p	R
	19.1	3.86	0.191	22.0	5.46	0.175	17.2	5.66	0.211
	22.6	4.14	.169	11.1	4.98	0.169	23.6	5.89	0.173
	23.8	4.40	.201	20.8	4.57	0.205	20.8	6.45	0.201
	20.8	3.84	.192	....	....	....	....	....	....
	21.5	3.80	.217	....	....	....	....	....	....
	20.0	3.99	0.220	....	....	....	....	....	....
Means.....	21.3	4.00	**0.198**	18.0	5.00	**0.183**	20.5	6.00	**0.195**

p	6.50–7.50			7.50–8.50			8.50–9.50		
	t	p	R	t	p	R	t	p	R
	25.4	6.60	0.171	20.0	7.80	0.169	24.1	9.42	0.156
	21.5	7.08	.166	19.5	8.36	.159	20.1	9.32	.166
	21.0	7.14	.187	18.8	8.25	.138	23.3	8.54	.163
	21.2	6.60	.175	20.3	7.54	.171	18.0	9.16	.139
	17.9	7.44	.173	21.5	8.48	.188	24.2	8.96	.173
	20.3	7.10	.157	24.4	8.36	0.190	19.5	8.86	.171
	15.7	6.80	0.177	....	....	....	20.6	8.61	0.179
Means.....	20.4	6.98	**0.173**	20.7	8.13	**0.169**	21.4	8.98	**0.164**

p	9.50–10.50			11.90–13.24					
	t	p	R	t	p	R			
	21.4	9.88	0.162	18.6	11.90	0.147	....	....	....
	25.0	9.98	.178	18.9	13.24	0.145	....	....	....
	22.8	10.20	.158	....	....	....	....	....	....
	138.	10.40	0.138	....	....	....	....	....	....
Means.....	20.8	10.12	**0.159**	18.8	12.57	**0.146**			

other influences. The mean value of the irradiation corresponding to great haziness differs only within the limits of error (1 per cent) from the mean value corresponding to a more clear sky. As long as the diffusing particles are small and no clouds

are formed, the diffusing particles seem not to have the faculty to absorb or radiate the long waves, with which we here are dealing. This opinion is supported also by the statement of Very,[1] that "The experiments with dust-laden air have indicated that the addition of a small amount of solid matter, diffused through a large volume of air, does not change the radiating power of the latter

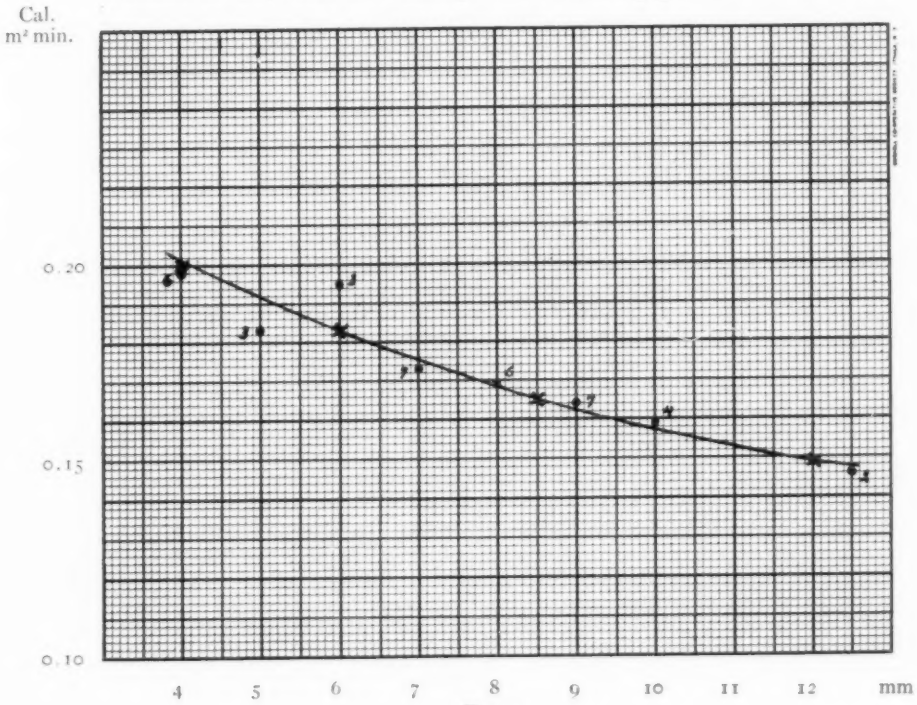

FIG. 2

. . . = observed curve; ×××=calculated curve. Numbers indicate numbers of observations for every mean value.

perceptibly." The results of these experiments are in full agreement with my observations of the radiation from the sky.

The experimental curve is well satisfied through the following relation:

$$R = 0.109 + 0.134 \cdot e^{-0.10p}$$

which in its general form has been founded on theoretical considerations.

[1] Very, *Atmospheric Radiation*. Washington, 1900.

The question is now to what extent this relation, as it is obtained for a certain atmospheric pressure, a certain height above sea-level, and a certain temperature of the earth can be regarded as satisfying more general conditions. Only thorough investigations can answer this question. It may, however, be assumed that the atmospheric radiation, at least for low altitudes, is practically independent of the total atmospheric pressure. The effect of the temperature conditions of the earth and the atmosphere on the radiation may be much larger. Our first step, if we wished to take account of the influence of the temperature, should be to substitute for p the density of the water-vapor as a function of the temperature, and to express the radiation from the atmosphere as a whole by a law similar to Stefan's radiation law.

From the result obtained, we can draw no conclusions about the radiation for the case when p is less than about 4 mm. If the pressure is less than 4 mm, many of the terms that we have regarded as constant in the expression (3) will begin to vary with the density of the radiating layer and hence the curve (Fig. 2) will increase much more rapidly for low pressures than would be expected from the behavior of the curve in the investigated interval.

For the case when p approaches very great values, the formula seems to indicate that the radiation approaches a value of about $0.11 \frac{\text{cal.}}{\text{cm}^2 \text{ min.}}$, which shows that the water-vapor even in very thick layers is almost transparent for certain wave-lengths. Here, however, we must consider that the conditions are complicated through the temperature fall in the radiating atmospheric layer. In great concentration of the water-vapor the temperature fall will be of little importance, the air layers that influence the radiation being relatively thin and lying near the earth's surface. If the concentration is small, however, the radiation from the earth will penetrate to colder air layers, or, what is the same, the radiation from colder layers will penetrate to the earth, and the assumption that the atmosphere has a constant temperature will be more or less incorrect.

SUMMARY

My observations have shown:

1. That the influence of the density of the water-vapor on the atmospheric radiation can, between certain limits, be expressed through an exponential formula.

A change in the water-vapor pressure from 12 to 4 mm will, under the conditions I have defined in the paper, increase the mean radiation from the earth's surface about 35 per cent. On the other hand, the absorption power for sun radiation will only vary between about 5 and 15 per cent for the mentioned pressure-interval. The importance of the humidity for the climate is clear from this consideration and from the fact that the loss of heat from the earth's surface is largely due to radiation.

2. That a slight haziness, as indicated by changes in the transmissive power of the atmosphere for visible rays (clouds not formed), seems to have no appreciable influence upon the radiation of the atmosphere.

CORNELL UNIVERSITY
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RADIAL MOTION IN SUN-SPOTS[1]

I. THE DISTRIBUTION OF VELOCITIES IN THE SOLAR VORTEX

By CHARLES E. ST. JOHN

In the spring of 1909 Mr. Evershed announced the remarkable discovery of the displacement of the Fraunhofer lines in the penumbrae of sun-spots. In brief, he found that practically all the lines of the reversing layer are shifted and that the stronger lines appear less affected than the weaker. He advanced the hypothesis that the displacements are due to the radial movement outward and tangential to the solar surface of the gases of the reversing layer. From his observations he concluded that the motion is accelerated outward but ceases abruptly at the limits of the penumbrae, that the movement is confined to the reversing layer, that the gases of the higher chromosphere do not share in the movement, but, on the contrary, show a tendency to move inward, and that the maximum velocity indicated by the majority of the lines is 1.57 km per second.[2]

In the summer of 1910 I began an extended investigation of the subject, using the spectrograph of the 60-foot tower telescope. By means of a simple occulting device, the spectra of the edges of the penumbrae directed toward the center and the limb of the sun, respectively, were obtained juxtaposed upon the photographic plate; and in what follows these edges will be referred to simply as the center and limb edges. The two diagrams show the details of the arrangement and the manner of using it. In position 1 of the occulting device the limb edge of the penumbra is tangent to the edge of the occulting bar at the point directly over the slit (*a*), which is parallel to the radius of the solar image passing through the spot. After making an exposure, the occulting bar is moved until the fiducial line (*c*) is directly over the slit, and

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 69.

[2] *Kodaikanal Observatory Bulletin*, No. XV; *Kodaikanal Observatory Memoirs*, 1, Pt. 1.

the image of the sun is moved parallel to the slit until the center edge of the penumbra is tangent to the central line at the point (*d*). The occulting bar is then moved into position 2, and the second exposure made. In the procedure described, the spectrum of the spot was not photographed, but by placing the center edge of the penumbra tangent to the edge of the occulting bar in its first position and by a similar change in the second position, the spectra of the limb edge and the center edge of the penumbra are side by side along the center of the plate with a spectrum of the spot on either side. This has the advantage that the distance of the point

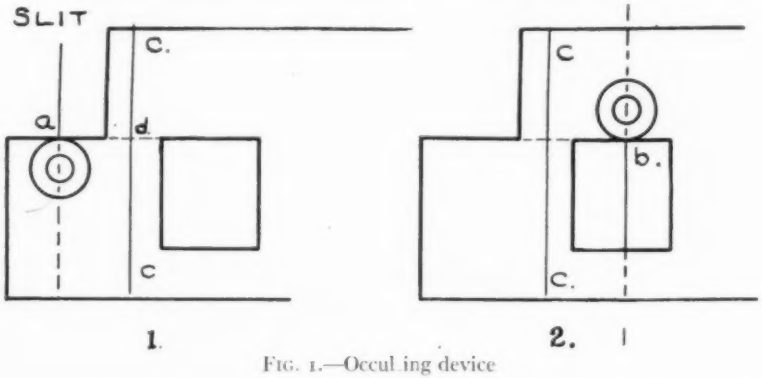


FIG. 1.—Occul ing device

measured from the center of the spot can be determined, and the whole course of the displaced line can be examined; but for purposes of measurement, the first plan was found more satisfactory. The displacement was doubled in either case, as on one edge of the penumbra the lines are shifted to the red, and on the other to the violet. The positions of the spots on a solar image 170 mm in diameter varied from 10 to 45 mm from the limb. The usual course of the line on such plates shows no sharp break and the displacement does not suddenly cease at the periphery of the penumbra, but the line gradually returns to its normal course. This differs from Mr. Evershed's observation, and seems to remove one great difficulty in explaining the displacement as due to motion.

There was a question whether the slight shifting of the solar image would not of itself introduce displacements caused by the change in the illumination of the grating. This was tested by

measurements of the atmospheric lines wherever they appeared upon the plate, and the absence of any effect due to this cause or to instrumental displacements completely justified the method. On 54 plates the mean displacement of the atmospheric lines was +0.0003 Å.

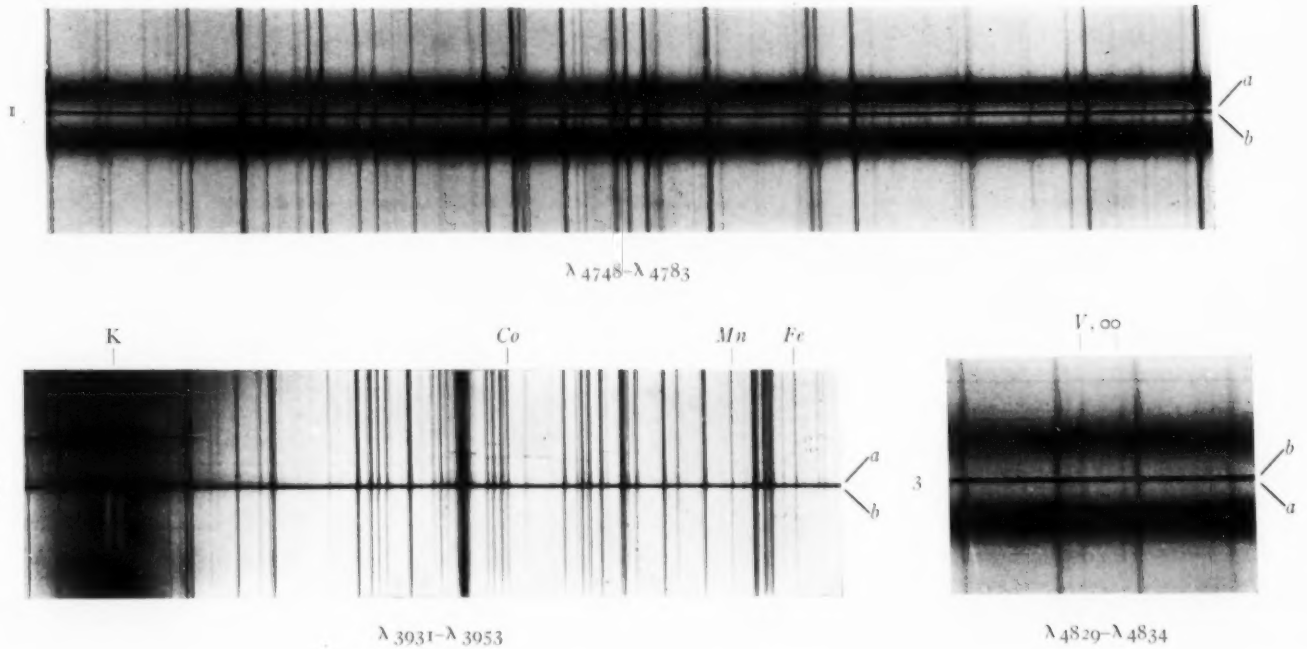
For measurement, the plate was first adjusted so that the edges of the spectra where they were opposed moved parallel to the screw. The cross-hair of the microscope was fixed parallel to the normal direction of the lines by setting upon the two parts of the line on each side of the division and far enough from the penumbra to be undisturbed by the radial motion. The field of the microscope was sufficiently flat to allow of this. Measurements were made upon the points of the line that were equally distant from the horizontal cross-hair, which was central with respect to the two spectra, and these distances were equal for all lines. The plates in the violet and green were taken in the third-order spectrum and those in the yellow and the red in the second order, the dispersion in the two cases being 1 mm = 0.56 Å. and 1 mm = 0.86 Å. It was found that for such lines as D_1 and D_2 and H_α, the second order gained in accuracy over the third as much as it lost in dispersion, and the requisite intensity of the spectra was obtained by much shorter exposure time.

Observations were obtained upon the following regular spots which are identified by the Greenwich numbers. The diameters of the umbrae and penumbrae are given for the central meridian on an image 170 mm in diameter.

Spot No.	C.M. G.M.T.	Umbra	Penumbra	Spot No.	C.M. G.M.T.	Umbra	Penumbra
		mm	mm			mm	mm
6847..	1910 May 18.6	1.1	2.3	6942..	1911 Apr. 27.7	0.9	2.5
6864..	July 6.3	1.7	4.0	6944..	Apr. 28.7	1.1	3.0
6874..	Aug. 9.5	1.7	4.0	6945..	Apr. 28.9	0.5	1.5
6880..	Sept. 5.8	1.2	3.0	6951..	May 30.8	1.0	2.5
6886..	Oct. 26.9	0.9	2.5	6972..	Nov. 27.1	0.9	2.0
6940..	1911 Apr. 9.3	1.0	3.0				
				Mean		1.1	3.0

In laying out the program for what was expected to be a preliminary survey, it was not at first clear what lines would prove of the greatest interest. An examination of the blue region studied

PLATE XII



SPECTRUM OF THE EDGE OF THE PENUMBRA

a, Edge directed toward the limb. *b*, Edge directed toward the center of the disk

1. Relative displacements of strong and weak lines, indicating different velocities of outflow
2. Displacement of the K line of calcium, showing inflow
3. Large displacement and great strengthening of *V* lines of intensity ∞

by Mr. Evershed showed at once that the list should embrace a large number of lines of as diverse character as possible. The lines were selected on the following bases:

a) As many elements as possible to be included, in fact, 27 substances are represented in the list.

b) Lines known to originate in the higher levels of the chromosphere such as H, K, H_α, and the strongest lines of magnesium, aluminium, and iron.

c) Elements of exceptionally high atomic weight, and rare elements, particularly barium, lanthanum, cerium, lead, ytterbium, neodymium, and niobium.

d) Lines covering a wide range of intensities for each element.

e) A very large number of lines of all intensities of some one element represented by many lines, such as iron.

f) Lines of peculiar interest, such as the enhanced lines, and lines belonging to different pressure groups.

The program has included 506 lines which fulfil the conditions indicated in sufficient numbers to permit statistical treatment, and they are distributed as follows: violet 268, blue-green 164, yellow-red 74.

In the first three columns of Table I are the wave-lengths, identifications, and intensities, as given in Rowland's table. The fourth column contains the absolute displacements in Ångströms reduced to the limb; the fifth column, the number of plates; and the sixth column, the mean deviations. These are not a measure of the accuracy of the measurements, but include the deviation from plate to plate, which is the larger element involved. The displacements vary rapidly with the distance from the edge of the penumbra, and, with the utmost possible care in guiding, the slit cannot be set and rigorously held upon the same point with respect to the edge of the penumbra, so that plates taken in quick succession give different absolute displacements, but for each plate (45 cm long) the relative displacements of the various lines upon the plate are in the proper relation. If the position of the slit is changed by a fifth of a millimeter, the point of observation on the sun for the mean positions of the spots is shifted 2000 km toward or away from the axis of the spot, and for such changes in distance

the change in velocity is large. The seventh column under Δ' requires a word of explanation. As has just been said, the absolute values for different plates vary. If, therefore, upon any given plate it has for any reason been impossible to measure the displacement of a line appearing upon the other plates, the omission of this line from the plate under consideration might appreciably affect the final mean if the plate as a whole showed displacements differing greatly from the mean of the other plates. The values under Δ' are obtained in the following way: when the displacement of a line in the list has not been measured on a given plate because of some defect or lack of intensity or definition, an interpolated value for the displacement of the line on this plate has been used in determining the final mean. The interpolation was carried out as follows: considering only the lines common to all the plates, the ratio was found between the displacements on the given plate and the mean displacements on the other plates. This ratio is the operator by which the required displacement is found from the mean displacement of the same line on the other plates. The procedure not only eliminated the irregularities introduced by the omission of the line from one or more plates, but equalized the weights of the observations for neighboring lines. The mean values are the ones used in the discussion. As a matter of fact, the greater number of the displacements under Δ' agree with those under Δ. Changes occur in the case of 97 out of 506 lines. In 63 cases the correction is ± 0.001 Å., in 26 cases, ± 0.002 Å., and in 8 cases, ± 0.003 Å. The adjustments have a random distribution and produce no systematic effect. In the eighth column the displacements are reduced to λ 5000; and in the ninth column, under character and group, are given the grouping of the iron and titanium lines suggested by Gale and Adams,[1] with the addition of group *e* and the subdivision of group *d* suggested in a paper by Miss Ware and myself on the iron standards,[2] also the enhanced lines, and some probable blends.

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 58; *Astrophysical Journal*, **35**, 10–47, 1912.

[2] *Contributions from the Mount Wilson Solar Observatory*, No. 61; *Astrophysical Journal*, **36**, 14, 1912.

TABLE I

RELATIVE DISPLACEMENTS OF THE FRAUNHOFER LINES AT THE LIMB AND CENTER EDGES OF THE PENUMBRAE OF ECCENTRICALLY LOCATED SPOTS

λ	Element	Intensity	Δ	No. of Plates	Mean Deviation	Δ′	Δ′ Reduced to λ 5000	Character or Group
3624.258...	*Ca*	3	+0.012	3	4	+0.012	+0.016	
3627.953...	*Co*	4	+0.016	3	3	+0.016	+0.022	
3628.967...	*La*	2	+0.019	3	11	+0.019	+0.026	
3629.877...	*Mn*	1	+0.017	3	5	+0.017	+0.023	
3630.045...	*Ni*	1	+0.024	3	3	+0.024	+0.033	
3631.124...	*Ca*	2	+0.016	3	4	+0.016	+0.022	
3639.943...	*Cr*	2	+0.017	3	4	+0.017	+0.023	
3646.335...	*Ti*	1	+0.012	3	3	+0.012	+0.016	
3649.137...	*Cr*	1	+0.014	3	2	+0.014	+0.019	
3652.691...	*Co*	3	+0.013	3	4	+0.013	+0.018	
3653.637...	*Ti*	5	+0.008	3	3	+0.008	+0.011	
3659.663...	*Fe*	5	+0.014	3	6	+0.014	+0.019	
3662.096...	*Ni*	3	+0.015	5	4	+0.015	+0.021	
3670.566...	*Ni*	5	+0.011	5	2	+0.011	+0.015	
3686.926...	*Cr*	1	+0.016	5	6	+0.016	+0.022	
3687.234...	*Fe*	3	+0.010	5	3	+0.010	+0.014	
3687.610...	*Fe*	6	+0.007	3	1	+0.007	+0.008	
3688.210...	*V*	1	+0.018	4	5	+0.018	+0.024	
3690.599...	*Fe*	2	+0.017	5	2	+0.017	+0.023	
3692.364...	*V*	1	+0.017	5	4	+0.017	+0.023	
3692.790...	*Fe*	2	+0.020	5	4	+0.020	+0.027	
3693.616...	*Co*	1	+0.021	5	9	+0.021	+0.028	
3694.344...	*Yt*	3	+0.020	5	6	+0.020	+0.027	
3694.576...	*La*	1	+0.027	5	3	+0.027	+0.036	
3695.194...	*Fe*	5	+0.013	5	1	+0.013	+0.017	
3697.567...	*Fe*	5	+0.012	4	5	+0.012	+0.016	
3698.744...	*Fe*	4	+0.014	5	3	+0.014	+0.019	
3699.283...	*Fe*	3	+0.019	5	4	+0.019	+0.026	
3701.234...	*Fe*	8	+0.007	4	6	+0.007	+0.009	
3702.170...	*Fe*	4	+0.019	4	2	+0.019	+0.025	
3702.639...	*Fe*	4	+0.017	5	4	+0.017	+0.023	
3704.603...	*Fe*	4	+0.016	5	3	+0.016	+0.021	
3704.840...	*V*	1	+0.016	5	3	+0.016	+0.022	
3706.363...	*Fe*	3	+0.018	3	4	+0.017	+0.023	
3707.186...	*Fe*	5	+0.014	5	7	+0.014	+0.019	
3707.600...	*Co*	2	+0.005	5	5	+0.005	+0.007	
3707.702...	*Ti*	2	+0.013	5	5	+0.013	+0.017	
3708.964...	*Co*	1	+0.015	5	5	+0.015	+0.020	
3709.389...	*Fe*	8	+0.002	4	5	+0.002	+0.003	*b*
3710.431...	*Y*	3	+0.015	5	6	+0.016	+0.020	
3711.364...	*Fe*	4	+0.014	5	4	+0.014	+0.019	
3711.552...	*Fe*	3	+0.015	5	1	+0.015	+0.020	
3716.591...	*Fe*	7	+0.012	4	2	+0.012	+0.016	
3717.539...	*Ti*	2	+0.017	5	3	+0.017	+0.023	
3718.554...	*Fe*	4	+0.015	5	1	+0.015	+0.020	
3720.084...	*Fe*	40	+0.003	3	1	+0.003	+0.004	
3724.970...	*Ni*	1	+0.018	5	8	+0.018	+0.024	
3879.716...	*CN*	1	+0.015	9	7	+0.015	+0.020	
3879.824...	*CN*	0	+0.021	7	5	+0.021	+0.028	
3880.105...	*CN*	1	+0.012	7	6	+0.012	+0.015	

TABLE I—*Continued*

λ	Element	Intensity	Δ	No. of Plates	Mean Deviation	Δ′	Δ′ Reduced to λ 5000	Character or Group
3880.205	*CN*	0	+0.017	5	6	+0.017	+0.022	
3882.267	*CN*	1	+0.014	7	4	+0.014	+0.019	
3895.119	*Co*	3	+0.012	9	5	+0.012	+0.015	
3895.377	*Ti*	2	+0.019	7	5	+0.020	+0.025	
3895.583	*Mn*	3	+0.008	7	6	+0.008	+0.010	
3895.803	*Fe*	7	+0.004	9	8	+0.004	+0.005	*a*
3897.596	*Fe*	2	+0.009	9	6	+0.009	+0.012	
3898.032	*Fe*	3	+0.007	9	8	+0.007	+0.009	
3898.531	*Mn*	2	+0.014	9	7	+0.014	+0.018	
3899.171	*Fe*	3	+0.013	9	5	+0.013	+0.017	
3901.114	*Ti*	1	+0.017	8	8	+0.017	+0.021	*a*
3902.399	*V*	3	+0.012	9	6	+0.012	+0.015	
3904.926	*Ti*	3	+0.013	9	7	+0.013	+0.017	*a*
3905.660	*Si*	12	0.000	9	5	0.000	0.000	Enh.–*Cr*?
3906.438	*Co*	2	+0.010	9	6	+0.010	+0.013	
3906.628	*Fe*	10	+0.003	9	5	+0.003	+0.004	*a*
3908.900	*Cr*	4	+0.011	9	8	+0.011	+0.014	
3911.963	*Sc*	2	+0.013	8	4	+0.013	+0.017	
3913.123	*Ni*	2	+0.016	8	6	+0.016	+0.020	
3916.879	*Fe*	5	+0.009	9	5	+0.009	+0.011	
3933.825	K_3		−0.050	9	16	−0.050	−0.064	
3933.825	K_2		−0.036	9	14	−0.036	−0.046	
3941.637	*Cr*	3	+0.014	11	6	+0.014	+0.018	
3941.878	*Co*	2	+0.015	11	7	+0.015	+0.019	
3944.160	*Al*	15	+0.001	12	6	+0.001	+0.001	
3947.142	*Fe*	3	+0.011	12	4	+0.011	+0.014	
3947.522	?	2	+0.014	4	7	+0.014	+0.018	
3947.675	*Fe*	4	+0.009	5	3	+0.009	+0.011	
3947.918	*Ti*	2	+0.011	11	7	+0.013	+0.016	*a*
3948.818	*Ti*	4	+0.009	14	5	+0.009	+0.011	*a*
3948.925	*Fe*	4	+0.009	14	7	+0.009	+0.011	
3949.039	*Ca*	1	+0.017	11	6	+0.018	+0.022	
3950.102	*Fe*	15	+0.010	14	5	+0.010	+0.013	
3950.497	*V*	5	+0.013	14	5	+0.013	+0.016	
3956.603	*Fe*	4	+0.010	16	5	+0.010	+0.013	
3956.879	*Fe*	6	+0.009	15	5	+0.009	+0.011	
3958.073	*Co*	2	+0.017	15	5	+0.018	+0.021	
3958.877	*Fe*	1	+0.022	7	5	+0.021	+0.026	
3960.422	*Fe*	4	+0.014	16	5	+0.014	+0.017	
3961.674	*Al*	20	0.000	16	6	0.000	0.000	
3962.995	*Ti*	3	+0.012	16	5	+0.012	+0.015	*a*
3963.831	*Co*	3	+0.010	16	5	+0.010	+0.013	
3968.825	H_3		−0.049	15	15	−0.049	−0.062	
3968.825	H_2		−0.033	14	21	−0.033	−0.042	
3969.413	*Fe*	10	+0.004	16	8	+0.004	+0.005	
3971.475	*Fe*	5	+0.008	16	4	+0.008	+0.010	
3974.774	*Ni*	2	+0.015	8	5	+0.014	+0.018	
3977.891	*Fe*	6	+0.010	17	5	+0.010	+0.013	*b*
3980.779	*Fe*	1	+0.014	9	6	+0.014	+0.018	
3981.248	*Fe*	2	+0.017	10	5	+0.017	+0.021	
3981.917	*Ti*	4	+0.013	9	5	+0.013	+0.016	*a*
3982.745	*V*	3	+0.013	9	5	+0.013	+0.016	
3984.294	*Mn*	2	+0.021	9	7	+0.021	+0.026	

TABLE I—*Continued*

λ	Element	Intensity	Δ	No. of Plates	Mean Deviation	Δ′	Δ′ Reduced to λ 5000	Character or Group
3984.479	*Cr*	2	+0.024	9	7	+0.024	+0.030	
3986.321	*Fe*	3	+0.011	8	3	+0.011	+0.014	
3989.912	*Ti*	4	+0.008	9	6	+0.008	+0.010	*a*
3990.011	*Fe*	3	+0.012	11	7	+0.012	+0.015	
3990.525	*Fe*	2	+0.016	11	4	+0.016	+0.020	
3991.580	*Fe*	1	+0.020	11	6	+0.020	+0.025	
3993.246	*Fe*	2	+0.026	10	8	+0.025	+0.031	
3994.265	*Fe*	4	+0.015	11	8	+0.015	+0.019	
3994.828	*Nd?*	2	+0.018	11	7	+0.018	+0.022	
3995.463	*Co*	5	+0.011	11	5	+0.011	+0.014	
3995.899	*La*	1 N	+0.014	11	9	+0.014	+0.018	
3996.140	*Fe*	3	+0.015	12	8	+0.015	+0.019	
3997.115	*Fe*	2	+0.019	12	9	+0.019	+0.024	
3997.547	*Fe*	4	+0.012	12	6	+0.012	+0.015	*b*
3998.053	*Co*	4	+0.017	12	10	+0.017	+0.021	
3998.205	*Fe*	4	+0.014	12	7	+0.014	+0.018	
3998.790	*Ti*	4	+0.012	12	5	+0.012	+0.015	*a*
4000.403	*Fe*	2	+0.023	12	11	+0.023	+0.029	
4000.611	*Fe*	2	+0.016	12	7	+0.016	+0.020	
4001.595	*Cr*	1	+0.022	11	8	+0.021	+0.026	
4001.814	*Fe*	3	+0.016	12	9	+0.016	+0.020	
4006.304	*Ni*	1	+0.024	12	10	+0.024	+0.030	
4006.464	*Fe*	2	+0.020	12	9	+0.020	+0.025	
4006.776	*Fe*	3	+0.015	11	6	+0.017	+0.021	
4010.927	*Fe*	2	+0.022	12	9	+0.022	+0.028	
4011.080	*Fe*	2	+0.026	12	8	+0.026	+0.022	
4013.964	*Fe*	5	+0.020	12	9	+0.020	+0.025	
4016.574	*Fe*	2	+0.022	12	10	+0.022	+0.027	
4018.420	*Fe*	3	+0.022	12	11	+0.022	+0.027	
4020.547	*Sc*	1	+0.014	11	8	+0.014	+0.017	
4021.057	*Co*	3	+0.018	12	7	+0.018	+0.022	
4023.834	*Sc*	2	+0.026	12	7	+0.026	+0.031	
4024.726	*Ti*	3	+0.016	12	7	+0.016	+0.019	*a*
4035.752	*Co*	2	+0.015	10	4	+0.016	+0.019	
4055.701	*Mn*	6	+0.018	12	9	+0.018	+0.021	Enh.–*Fe?*
4059.081	*Mn*	3	+0.018	12	6	+0.018	+0.021	
4063.759	*Fe*	20	0.000	12	10	0.000	0.000	*b*
4066.524	*Co*	2	+0.020	12	8	+0.020	+0.024	
4070.431	*Mn*	3	+0.023	12	9	+0.023	+0.028	
4077.885	*Sr*	8	−0.002	12	7	−0.002	−0.002	Enh.
4078.631	*Ti*	3	+0.018	10	7	+0.017	+0.021	*a*
4079.570	*Mn*	3	+0.018	12	9	+0.018	+0.022	
4083.095	*V–Mn*	4	+0.020	12	10	+0.020	+0.024	
4086.861	*La*	1	+0.026	12	12	+0.026	+0.031	
4095.094	*Ca?*	4	+0.020	12	9	+0.020	+0.024	
4099.941	*V*	2	+0.025	12	5	+0.025	+0.030	
4102.000	*Hδ*	40	−0.004	11	14	−0.004	−0.005	
4103.097	*Si–Mn*	5	+0.017	12	7	+0.017	+0.020	
4109.609	*Nd?*	1	+0.016	12	6	+0.016	+0.019	
4110.691	*Co*	4	+0.016	11	7	+0.016	+0.019	
4111.509	*Co*	1	+0.028	12	11	+0.028	+0.034	
4116.859	*Nd?*	1	+0.027	9	17	+0.025	+0.030	
4118.934	*Co*	4	+0.013	12	5	+0.013	+0.016	

TABLE I—*Continued*

λ	Element	Intensity	Δ	No. of Plates	Mean Deviation	Δ′	Δ′ Reduced to λ 5000	Character or Group
4123.384	*La*	2	+0.024	11	14	+0.023	+0.028	
4129.337	*Ce–*	3	+0.022	12	7	+0.022	+0.026	
4130.804	*Ba*	2	+0.027	11	10	+0.027	+0.033	Enh.
4131.271	*Mn*	1	+0.027	11	11	+0.026	+0.031	
4132.100	*V*	2	+0.011	10	8	+0.011	+0.013	
4132.235	*Fe*	10	+0.002	9	7	+0.002	+0.002	*b*
4133.755	*Fe*	2	+0.022	12	9	+0.022	+0.026	
4134.840	*Fe*	5	+0.014	11	5	+0.014	+0.017	*b*
4136.678	*Fe*	4	+0.023	11	7	+0.023	+0.028	
4137.156	*Fe*	6	+0.016	12	8	+0.016	+0.019	
4137.809	*Ce*	1	+0.014	12	10	+0.014	+0.017	
4142.330	*Cr*	2	+0.026	12	11	+0.026	+0.031	
4142.624	*Cr*	2	+0.027	4	12	+0.026	+0.031	
4147.645	*Mn*	1	+0.023	12	9	+0.023	+0.028	
4149.360	*Zr*	2	+0.016	12	9	+0.016	+0.019	
4150.608	*Co*	1	+0.017	9	6	+0.017	+0.020	
4157.948	*Fe*	5	+0.015	14	9	+0.015	+0.018	
4161.961	*Sr*	1	+0.025	13	10	+0.025	+0.030	
4167.884	*CN*	1	+0.026	9	8	+0.027	+0.032	
4168.133	*Ni*	2	+0.020	14	10	+0.020	+0.024	
4179.025	*Fe*	3	+0.018	17	9	+0.018	+0.022	
4180.970	*CN*	2	+0.017	16	10	+0.017	+0.020	
4183.480	*Zr*	1	+0.022	8	12	+0.024	+0.029	
4183.619	*Z*	2	+0.024	12	10	+0.024	+0.029	
4184.472	*Ti*	2	+0.022	16	11	+0.022	+0.026	
4195.006	*Cr*	1	+0.020	7	7	+0.020	+0.024	
4196.609	*La*	2	+0.023	16	9	+0.024	+0.029	
4196.837	*Fe*	1	+0.020	16	10	+0.020	+0.024	
4197.257	*CN*	2	+0.021	16	10	+0.021	+0.025	
4204.163	*La*	4	+0.020	8	9	+0.020	+0.025	
4216.136	*CN*	1	+0.022	13	8	+0.022	+0.026	
4225.020	*Cr*	2	+0.021	13	10	+0.021	+0.025	
4226.904	*Ca*	20	−0.002	11	7	−0.002	−0.002	
4227.606	*Fe*	4	+0.010	11	10	+0.010	+0.012	
4232.111	*Nb?*	1	+0.029	10	11	+0.030	+0.035	
4233.328	*Mn, Fe*	4	+0.018	10	10	+0.017	+0.020	
4233.772	*Fe*	6	+0.012	10	10	+0.012	+0.014	*d*
4236.112	*Fe*	8	+0.003	11	7	+0.003	+0.003	*d*
4236.429	*Ni*	1	+0.024	10	14	+0.024	+0.028	
4238.970	*Fe*	5	+0.015	10	6	+0.015	+0.018	
4240.872	*Cr*	1	+0.022	9	6	+0.022	+0.026	
4246.996	*Sc*	5	+0.013	8	12	+0.013	+0.015	
4250.287	*Fe*	8	+0.014	7	7	+0.014	+0.016	*c*
4253.157	*Mn*	1	+0.027	6	6	+0.028	+0.033	
4254.505	*Cr*	8	+0.008	7	6	+0.008	+0.009	
4257.815	*Mn*	2	+0.022	6	11	+0.023	+0.027	
4258.477	*Fe*	2	+0.022	7	12	+0.022	+0.026	
4260.640	*Fe*	10	+0.003	5	4	+0.003	+0.003	*c*
4262.142		1	+0.024	6	12	+0.023	+0.027	
4266.080	*Mn*	2	+0.024	7	11	+0.024	+0.028	
4271.325	*Fe*	6	+0.009	7	4	+0.009	+0.010	
4271.934	*Fe*	15	−0.005	7	4	−0.005	−0.006	*b*
4273.643	*Zr*	2N	+0.021	7	9	+0.021	+0.024	

TABLE I—*Continued*

λ	Element	Intensity	Δ	No. of Plates	Mean Deviation	Δ′	Δ′ Reduced to λ 5000	Character or Group
4274.746	*Ti*	2	+0.016	7	10	+0.016	+0.019	
4274.958	*Cr*	7	+0.002	7	9	+0.002	+0.002	
4277.544	*Cr*	0	+0.023	4	10	+0.026	+0.030	
4281.257	*Mn*	2	+0.018	7	8	+0.018	+0.021	
4282.565	*Ti*	5	+0.012	7	7	+0.012	+0.014	
4283.169	*Ca*	4	+0.017	7	9	+0.017	+0.020	
4284.382	*Cr*	2	+0.023	7	10	+0.023	+0.027	Enh.
4284.838	*Ni*	1	+0.030	7	13	+0.030	+0.035	
4287.158	*La*	2	+0.017	6	13	+0.019	+0.022	
4287.566	*Ti*	1	+0.026	7	8	+0.026	+0.031	*a*
4289.237	*Ti*	2	+0.022	7	7	+0.022	+0.026	*a*
4289.525	*Ca*	4	+0.015	7	7	+0.015	+0.018	
4290.377	*Ti*	2	+0.013	7	10	+0.013	+0.015	Enh.
4291.630	*Fe*	2	+0.015	7	8	+0.015	+0.018	*a*
4294.936	*Zr*	2	+0.018	7	8	+0.018	+0.021	
4296.044	*Ni*	1	+0.020	7	10	+0.020	+0.023	
4299.149	*Ca*	3	+0.015	7	8	+0.015	+0.018	
4299.803	*Ti*	2	+0.016	7	7	+0.016	+0.019	*a*
4300.211	*Ti*	3	+0.007	7	4	+0.007	+0.008	Enh.
4300.732	*Ti*	2	+0.018	7	11	+0.018	+0.021	*a*
4302.085	*Ti*	2	+0.016	7	6	+0.016	+0.019	Enh.
4302.353	*Fe*	2	+0.019	5	8	+0.019	+0.022	
4302.692	*Ca*	4	+0.011	7	3	+0.011	+0.013	
4304.882	*Zr*	0	+0.020	4	9	+0.020	+0.023	
4306.078	*Ti*	4	+0.015	7	5	+0.015	+0.015	*a*
4313.034	*Ti*	3	+0.010	6	6	+0.011	+0.013	Enh.
4314.248	*Sc*	3	+0.016	7	7	+0.016	+0.018	
4314.964	*Ti*	1	+0.026	5	8	+0.025	+0.029	*d*?
4315.138	*Ti*	3	+0.009	6	5	+0.010	+0.011	
4320.907	*Sc*	3	+0.017	7	9	+0.017	+0.020	
4325.152	*Sc*	4	+0.012	7	7	+0.012	+0.014	
4325.939	*Fe*	8	+0.006	7	7	+0.006	+0.007	*b*
4328.080	*Fe*	2	+0.018	7	14	+0.018	+0.021	
4331.811	*Ni*	2	+0.021	7	10	+0.021	+0.024	
4333.925	*La*	1 N	+0.029	5	10	+0.026	+0.030	
4337.216	*Fe*	5	+0.015	7	5	+0.015	+0.017	*b*
4338.084	*Ti*	4	+0.014	7	5	+0.014	+0.016	Enh.
4338.430	*Fe*	1	+0.025	6	10	+0.025	+0.029	
4340.634	*Hγ*	20	−0.028	4	12	−0.029	−0.033	
4344.670	*Cr*	4	+0.016	7	4	+0.016	+0.018	
4352.083	*Ng*	5	+0.013	7	5	+0.013	+0.015	
4352.908	*Fe*	4	+0.015	7	8	+0.015	+0.017	*b*
4359.784	*Cr*	3	+0.018	7	11	+0.018	+0.021	
4359.907	*Zr*	0	+0.016	4	9	+0.019	+0.022	
4369.941	*Fe*	4	+0.018	6	9	+0.018	+0.021	*b*
4374.981	*Zr*	0	+0.012	4	7	+0.015	+0.017	
4376.107	*Fe*	6	+0.014	7	9	+0.014	+0.016	*a*
4377.948	*Fe*	1	+0.030	7	12	+0.030	+0.034	
4379.396	*V*	4	+0.016	7	8	+0.016	+0.018	
4380.326	*Co*	2 N	+0.031	7	17	+0.031	+0.035	
4383.720	*Fe*	15	−0.003	5	18	−0.003	−0.003	*b*
4385.548	*Fe*	2	+0.021	7	12	+0.021	+0.024	Enh.
4387.220	*Pb*	1 N	+0.026	7	10	+0.026	+0.030	Enh.

TABLE I—*Continued*

λ	Element	Intensity	Δ	No. of Plates	Mean Deviation	Δ′	Δ′ Reduced to λ 5000	Character or Group
4390.149	*V*	2	+0.020	7	10	+0.020	+0.023	
4400.555	*Sc*	3	+0.016	7	9	+0.016	+0.018	
4400.738	*V*	1	+0.021	7	8	+0.021	+0.024	
4404.927	*Fe*	10	+0.003	4	8	+0.003	+0.003	*b*
4408.364	*V*	2	+0.027	6	8	+0.027	+0.030	
4410.683	*Ni*	2	+0.028	6	11	+0.026	+0.029	
4634.254	*Cr*	2	+0.033	10	10	+0.032	+0.034	
4636.027	*Fe*	2	+0.035	14	14	+0.035	+0.038	
4637.685	*Fe*	5	+0.028	17	9	+0.028	+0.030	
4638.193	*Fe*	4	+0.026	16	8	+0.027	+0.029	
4643.645	*Fe*	4	+0.030	17	12	+0.030	+0.032	
4646.347	*Cr*	5	+0.018	18	6	+0.018	+0.019	
4648.835	*Ni*	4	+0.026	17	7	+0.026	+0.028	
4651.461	*Cr*	4	+0.024	17	8	+0.024	+0.026	
4652.343	*Cr*	5	+0.023	17	6	+0.023	+0.025	
4656.644	*Ti*	3	+0.034	3	19	+0.034	+0.036	
4662.149	*Fe?*	1	+0.030	3	11	+0.030	+0.032	
4667.626	*Fe*	4	+0.012	3	6	+0.013	+0.013	
4667.768	*Ti*	3	+0.027	17	8	+0.027	+0.029	*a*
4669.354	*Fe*	3	+0.035	3	12	+0.035	+0.037	*a*
4675.294	*Ti*	1 N	+0.041	14	10	+0.040	+0.043	*a*
4678.347	*Cd*	3 N	+0.039	16	7	+0.038	+0.041	
4679.027	*Fe*	6	+0.023	18	10	+0.023	+0.025	
4679.409	*Ni*	2	+0.038	12	11	+0.037	+0.039	Enh.
4680.317	*Zn*	1	+0.028	10	8	+0.025	+0.027	
4682.088	*Ti*	3	+0.029	18	8	+0.029	+0.031	
4683.745	*Fe*	3	+0.029	3	5	+0.029	+0.031	
4685.452	*Ca*	2 N	+0.034	18	10	+0.034	+0.036	
4686.395	*Ni*	3	+0.035	17	10	+0.035	+0.037	
4688.357	*Fe*	2	+0.036	3	7	+0.036	+0.038	
4701.714	*Ni*	1	+0.038	17	9	+0.038	+0.040	
4703.177	*Ng*	10	+0.010	17	11	+0.010	+0.011	
4703.994	*Ni*	3	+0.035	17	13	+0.035	+0.037	
4705.131	*Fe*	4	+0.038	3	4	+0.038	+0.040	
4708.196	*Cr*	2	+0.033	38	33	+0.033	+0.035	
4708.846	*Ti*	2	+0.028	15	13	+0.031	+0.033	Enh.
4709.896	*Mn*	2	+0.031	18	9	+0.031	+0.033	
4715.946	*Ni*	4	+0.026	18	10	+0.026	+0.028	
4718.601	*Cr*	3	+0.040	18	12	+0.040	+0.042	
4722.342	*Zn*	3	+0.036	18	12	+0.036	+0.038	
4728.732	*Fe*	4	+0.037	3	5	+0.037	+0.039	
4730.897	*Cr*	1	+0.039	15	9	+0.038	+0.040	
4731.984	*Ni*	1	+0.030	3	4	+0.030	+0.032	
4732.640	*Ni*	1	+0.038	3	4	+0.038	+0.040	
4733.779	*Fe*	4	+0.027	18	16	+0.027	+0.028	
4736.031	*Fe*	3	+0.032	18	10	+0.032	+0.034	
4737.540	*Cr*	2	+0.034	16	10	+0.034	+0.036	
4739.291	*Mn*	3	+0.038	3	13	+0.038	+0.040	
4741.718	*Fe*	3	+0.034	18	12	+0.034	+0.036	
4745.992	*Fe*	4	+0.034	16	14	+0.033	+0.035	
4752.289	*Ni*	2	+0.041	16	16	+0.040	+0.042	
4752.613	*Ni*	3	+0.034	18	10	+0.034	+0.036	
4754.225	*Mn*	7	+0.022	18	10	+0.022	+0.023	

TABLE I—*Continued*

λ	Element	Intensity	Δ	No. of Plates	Mean Deviation	Δ′	Δ′ Reduced to λ 5000	Character or Group
4756.300	*Cr*	2	+0.026	18	13	+0.026	+0.027	
4756.705	*Ni*	3	+0.033	18	12	+0.033	+0.035	
4757.771	*Fe*	2	+0.038	3	13	+0.038	+0.040	
4758.308	*Ti*	1	+0.034	18	10	+0.034	+0.036	*a*
4759.463	*Ti*	2	+0.034	3	18	+0.034	+0.036	*a*
4761.718	*Mn*	3	+0.032	17	11	+0.031	+0.032	
4762.567	*Mn*	5	+0.027	18	10	+0.027	+0.028	
4762.820	*Ni*	1	+0.039	3	2	+0.039	+0.040	
4766.050	*Mn*	3	+0.026	18	8	+0.026	+0.027	
4766.621	*Mn*	3	+0.028	18	10	+0.028	+0.029	
4773.007	*Fe*	4	+0.028	3	11	+0.028	+0.029	
4779.634	*Fe*	1	+0.041	3	7	+0.041	+0.043	
4780.169	*Co*	2	+0.032	18	11	+0.032	+0.034	Enh.–*Ti?*
4783.613	*Mn*	6	+0.023	17	12	+0.025	+0.026	
4786.727	*Ni*	3	+0.021	3	11	+0.022	+0.023	
4787.003	*Fe*	2	+0.025	18	9	+0.025	+0.026	
4788.952	*Fe*	3	+0.039	3	15	+0.039	+0.040	
4789.528	*Cr*	2	+0.033	17	10	+0.034	+0.035	
4789.849	*Fe*	3	+0.029	18	14	+0.029	+0.030	
4793.045	*Co*	1	+0.040	12	14	+0.040	+0.042	
4799.598	*Fe*	1	+0.048	3	21	+0.048	+0.050	
4801.213	*Cr*	1	+0.047	3	9	+0.047	+0.049	
4803.072	*Fe*	2	+0.023	3	14	+0.023	+0.024	
4807.179	*Ni*	2	+0.035	17	8	+0.034	+0.035	
4810.724	*Zn*	3	+0.035	17	13	+0.035	+0.036	
4813.661	*Co*	1	+0.038	17	18	+0.038	+0.039	
4820.593	*Ti*	1	+0.039	13	15	+0.038	+0.039	*a*
4823.697	*Mn*	5	+0.019	17	12	+0.019	+0.020	
4829.214	*Ni*	3	+0.036	17	12	+0.036	+0.037	
5123.899	*Fe*	3	+0.022	16	13	+0.022	+0.021	
5129.336	*Ti?*	3	+0.019	17	8	+0.020	+0.019	Enh.
5129.546	*Ni*	2	+0.026	17	10	+0.026	+0.026	
5129.805	*Fe*	1	+0.035	10	9	+0.033	+0.032	
5131.642	*Fe*	2	+0.024	20	10	+0.024	+0.023	
5131.942	*Ni*	1	+0.030	15	12	+0.029	+0.028	
5137.250	*Ni*	3	+0.021	20	8	+0.021	+0.020	
5137.558	*Fe*	3	+0.020	20	8	+0.020	+0.019	
5141.918	*Fe*	3	+0.023	29	9	+0.023	+0.022	
5142.693	*Fe*	4d	+0.020	28	9	+0.021	+0.020	
5145.371	*Fe*	1	+0.028	27	10	+0.028	+0.027	
5145.636	*Ti*	0	+0.026	21	14	+0.027	+0.026	*a*
5146.659	*Ni–*	3	+0.024	29	9	+0.024	+0.023	
5147.652	*Ti*	0	+0.029	24	12	+0.028	+0.027	*a*
5148.222	*Fe*	2	+0.023	29	11	+0.023	+0.022	
5148.410	*Fe*	3	+0.021	28	8	+0.021	+0.020	
5151.020	*Fe*	4	+0.016	27	9	+0.016	+0.016	
5152.087	*Fe*	3	+0.022	27	10	+0.023	+0.022	
5152.361	*Ti*	0	+0.029	25	10	+0.031	+0.030	*a*
5155.303	*Ni*	1	+0.030	28	12	+0.030	+0.029	
5155.935	*Ni*	2	+0.026	30	10	+0.026	+0.025	
5159.231	*Fe*	2	+0.023	30	9	+0.023	+0.022	
5162.449	*Fe, C*	5	+0.019	29	9	+0.019	+0.019	
5165.588	*Fe*	2	+0.020	30	10	+0.020	+0.019	

TABLE I—*Continued*

λ	Element	Intensity	Δ	No. of Plates	Mean Deviation	Δ′	Δ′ Reduced to λ 5000	Character or Group
5168.832...	*Ni*	1	+0.026	30	9	+0.026	+0.025	
5171.778...	*Fe*	6	+0.013	29	9	+0.014	+0.013	
5172.856...	*Mg*	20	−0.010	30	12	−0.010	−0.010	
5173.917...	*Ti*	2	+0.019	30	7	+0.019	+0.018	*a*
5176.735...	*Ni*	1	+0.028	30	8	+0.028	+0.027	
5180.233...	*Fe*	1	+0.028	29	11	+0.028	+0.027	
5183.791...	*Mg*	30	−0.013	29	9	−0.013	−0.012	
5186.073...	*Ti*	2	+0.021	30	11	+0.021	+0.020	
5188.079...	*Fe*	1	+0.027	29	10	+0.028	+0.027	
5188.863...	*Ti*	2	+0.015	30	8	+0.015	+0.014	Enh.
5189.018...	*Ca*	3	+0.021	29	10	+0.021	+0.020	
5191.629...	*Fe*	4	+0.014	29	9	+0.014	+0.013	
5192.523...	*Fe*	5	+0.012	30	10	+0.012	+0.012	
5193.139...	*Ti*	2	+0.022	29	9	+0.021	+0.020	*a*
5195.113...	*Fe*	4	+0.017	29	9	+0.017	+0.016	
5195.647...	*Fe*	2	+0.022	29	9	+0.022	+0.021	
5196.227...	*Fe*	1	+0.023	30	9	+0.023	+0.022	
5198.888...	*Fe*	3	+0.022	30	9	+0.022	+0.021	
5210.555...	*Ti*	3	+0.016	30	11	+0.016	+0.015	*a*
5217.552...	*Fe*	3	+0.018	30	9	+0.018	+0.017	
5218.085...	*Fe*	0	+0.029	22	9	+0.028	+0.027	
5218.369...	*Fe*	1	+0.027	29	9	+0.027	+0.026	
5219.875...	*Ti*	0	+0.028	15	8	+0.028	+0.027	*a*
5220.358...	*Ni*	0	+0.023	14	8	+0.023	+0.022	
5221.928...	*Cr*	0	+0.028	17	9	+0.029	+0.028	
5223.351...	*Fe*	0	+0.031	17	9	+0.031	+0.030	
5224.471...	*Ti*	0	+0.028	29	11	+0.028	+0.027	
5225.695...	*Fe*	2	+0.024	30	10	+0.024	+0.023	
5226.707...	*Ti*–	2	+0.020	30	8	+0.020	+0.019	Enh.
5230.030...	*Fe*	4	+0.021	30	10	+0.021	+0.020	
5233.122...	*Fe*	7	+0.007	25	8	+0.007	+0.007	*d*
5235.557...	*Fe*	1	+0.022	29	7	+0.022	+0.021	
5242.658...	*Fe*	2	+0.020	30	10	+0.020	+0.019	
5243.946...	*Fe*	1	+0.029	30	9	+0.029	+0.028	
5247.229...	*Fe*	1	+0.025	29	10	+0.025	+0.024	
5247.737...	*Cr*	2	+0.023	30	10	+0.023	+0.022	
5250.385...	*Fe*	2	+0.029	28	10	+0.028	+0.027	
5250.817...	*Fe*	3	+0.021	30	8	+0.021	+0.020	
5253.633...	*Fe*	2	+0.024	30	12	+0.024	+0.023	
5262.419...	*Ca*	3	+0.020	16	7	+0.020	+0.019	
5263.486...	*Fe*	4	+0.021	30	9	+0.021	+0.020	
5265.729...	*Ca*	3	+0.018	27	7	+0.018	+0.017	
5266.738...	*Fe*	6	+0.013	29	7	+0.013	+0.012	*d*
5281.971...	*Fe*	5	+0.019	26	8	+0.019	+0.018	
5283.802...	*Fe*	6	+0.013	26	10	+0.013	+0.012	
5284.281...	*Ti*	1	+0.026	26	8	+0.026	+0.025	
5288.705...	*Fe*	2	+0.025	25	8	+0.025	+0.024	
5296.872...	*Cr*	3	+0.021	22	10	+0.022	+0.021	
5297.555...	*Cr*	2	+0.021	23	9	+0.021	+0.020	
5298.194...	*Cr*	1	+0.021	22	10	+0.021	+0.020	
5298.455...	*Cr*	4	+0.016	22	9	+0.016	+0.015	
5298.672...	*Ti*	0	+0.023	18	7	+0.022	+0.021	*d*?
5300.929...	*Cr*	2	+0.025	22	10	+0.025	+0.024	

TABLE I—*Continued*

λ	Element	Intensity	Δ	No. of Plates	Mean Deviation	Δ′	Δ′ Reduced to λ 5000	Character or Group
5302.480	*Fe*	5	+0.015	22	11	+0.015	+0.014	
5307.541	*Fe*	3	+0.022	22	8	+0.022	+0.021	
5324.373	*Fe*	7	+0.006	21	11	+0.006	+0.006	*d*
5328.236	*Fe*	8?	+0.007	21	9	+0.007	+0.007	*a*
5335.050	*Co*	1	+0.026	12	8	+0.026	+0.024	
5340.121	*Fe*	6	+0.019	22	9	+0.019	+0.018	*d*
5342.890	*Co*	1	+0.028	13	12	+0.029	+0.027	
5345.991	*Cr*	5	+0.015	19	10	+0.015	+0.014	
5348.511	*Cr*	4	+0.017	19	10	+0.017	+0.016	
5349.653	*Ca*	4	+0.019	19	7	+0.019	+0.018	
5349.928	*Fe*	1	+0.028	16	14	+0.027	+0.025	
5598.524	*Fe*	1	+0.019	12	13	+0.019	+0.016	*e*
5598.711	*Ca*	4	+0.021	12	4	+0.021	+0.018	
5615.520	*Fe*	2	+0.025	12	6	+0.025	+0.022	
5615.877	*Fe*	6	+0.011	12	7	+0.011	+0.009	d_1
5624.245	*Fe*	1	+0.027	4	6	+0.027	+0.023	
5638.488	*Fe*	3	+0.029	12	8	+0.029	+0.025	d_1
5659.052	*Fe*	4	+0.013	10	7	+0.011	+0.009	d_1
5682.869	*Na*	5	+0.028	8	8	+0.028	+0.025	
5688.436	*Na*	6	+0.026	8	15	+0.026	+0.023	
5805.441	*Ni*	4	+0.038	26	9	+0.036	+0.031	
5806.950	*Fe*	5	+0.035	27	14	+0.035	+0.030	
5831.821	*Ni*	1	+0.032	19	10	+0.034	+0.029	
5838.592	*Fe*	1	+0.036	12	14	+0.037	+0.032	
5847.221	*Ni*	1	+0.034	21	11	+0.036	+0.031	
5848.342	*Fe*	3	+0.035	27	14	+0.035	+0.030	
5853.902	*Ba*	5?	+0.029	30	10	+0.029	+0.025	
5857.674	*Ca*	8	+0.025	34	11	+0.025	+0.022	
5857.976	*Ni*	3	+0.031	32	12	+0.030	+0.026	
5862.582	*Fe*	6	+0.029	34	10	+0.029	+0.025	
5866.675	*Ti*	3	+0.035	34	12	+0.035	+0.030	*a*
5890.186	*Na*	30	−0.008	34	10	−0.008	−0.007	
5893.079	*Ni*	4	+0.031	34	12	+0.031	+0.027	
5896.155	*Na*	20	−0.006	34	12	−0.006	−0.005	
5899.518	*Ti*	1	+0.041	18	9	+0.039	+0.033	*a*
5905.895	*Fe*	4	+0.025	8	11	+0.023	+0.020	
5910.197	*Fe*	1	+0.040	15	10	+0.037	+0.032	
5930.406	*Fe*	6	+0.034	8	12	+0.034	+0.029	
5934.881	*Fe*	5	+0.035	8	12	+0.035	+0.030	
5948.765	*Si*	6	+0.037	24	11	+0.036	+0.031	
5949.566	*Fe*	1	+0.033	19	14	+0.033	+0.028	
5953.386	*Ti*	1	+0.038	26	16	+0.038	+0.032	*a*
5956.923	*Fe*	4	+0.035	25	13	+0.035	+0.029	
5975.575	*Fe*	3	+0.033	21	8	+0.033	+0.027	*b*
5977.007	*Fe*	4	+0.028	4	6	+0.028	+0.022	*d*
5978.768	*Ti*	1	+0.037	17	12	+0.037	+0.031	*a*
5983.908	*Fe*	5	+0.028	4	14	+0.028	+0.023	*d*
5985.040	*Fe*	6	+0.024	4	10	+0.024	+0.020	*e*
5987.290	*Fe*	5	+0.016	4	3	+0.016	+0.013	*e*
6003.239	*Fe*	6	+0.024	4	19	+0.024	+0.020	*d*
6007.540	*Ni*	1	+0.033	3	14	+0.035	+0.030	
6008.186	*Fe*	4	+0.027	3	10	+0.030	+0.025	*e*
6008.785	*Fe*	6	+0.022	4	12	+0.022	+0.018	*d*

TABLE I—*Continued*

λ	Element	Intensity	Δ	No. of Plates	Mean Deviation	Δ′	Δ′ Reduced to λ 5000	Character or Group
6013.715...	*Mn*	6	+0.026	3	11	+0.028	+0.023	*d*
6016.861...	*Mn*	6	+0.029	4	11	+0.029	+0.024	*d*
6022.016...	*Mn*	6	+0.022	4	6	+0.022	+0.018	*d*
6027.274...	*Fe*	4	+0.021	3	8	+0.023	+0.019	*b*
6042.315...	*Fe*	3	+0.029	4	9	+0.029	+0.024	Enh.
6056.227...	*Fe*	5	+0.030	4	10	+0.030	+0.025	*c*
6065.709...	*Fe*	7	+0.018	3	3	+0.016	+0.013	*b*
6393.820...	*Fe*	7	+0.017	25	10	+0.017	+0.013	*b*
6400.217...	*Fe*	8	+0.016	24	8	+0.015	+0.012	*d*
6400.528...	*Fe*	2	+0.026	24	11	+0.026	+0.020	
6408.233...	*Fe*	5	+0.021	25	8	+0.021	+0.017	*d*
6411.865...	*Fe*	7	+0.019	25	9	+0.019	+0.015	*d*
6420.169...	*Fe*	4	+0.025	25	10	+0.025	+0.020	
6421.570...	*Fe*	7	+0.023	25	8	+0.023	+0.018	*b*
6431.066...	*Fe*	5	+0.021	25	9	+0.021	+0.017	*b*
6439.293...	*Ca*	8	+0.018	24	4	+0.018	+0.014	
6450.033...	*Ca*	6	+0.020	25	10	+0.020	+0.016	
6455.820...	*Ca*	2	+0.036	44	12	+0.035	+0.029	
6471.885...	*Ca*	5	+0.028	44	10	+0.027	+0.022	
6494.004...	*Ca*	6	+0.020	47	9	+0.020	+0.017	
6495.213...	*Fe*	8	+0.019	48	11	+0.017	+0.014	*b*
6496.688...	*Fe*	2	+0.038	30	12	+0.037	+0.030	
6497.128...	*Fe*	4	+0.020	30	9	+0.020	+0.016	
6499.168...	*Fe*	1	+0.039	30	12	+0.037	+0.031	
6499.880...	*Ca*	4	+0.030	29	11	+0.030	+0.024	
6563.045...	H_α		−0.064	29	26	−0.064	−0.050	
6569.460...	*Fe*	5	+0.039	28	14	+0.037	+0.030	
6573.030...	*Ca?*	1	+0.042	29	13	+0.041	+0.032	
6575.270...	*Fe*	2	+0.034	27	11	+0.032	+0.026	
6586.550...	*Ni*	1	+0.039	30	12	+0.037	+0.030	
6593.161...	*Fe*	6	+0.026	30	10	+0.024	+0.020	*b*
6594.121...	*Fe*	4	+0.029	30	10	+0.029	+0.022	
6597.807...	*Cr*	1	+0.041	30	17	+0.041	+0.031	
6633.995...	*Fe*	2	+0.045	30	18	+0.045	+0.034	
6643.876...	*Ni*	5	+0.033	30	12	+0.033	+0.025	

DISCUSSION

From a brief examination of the absolute displacements in the fourth column of Table I, it is evident that the larger displacements are associated with the longer wave-lengths. The mean displacements of the lines of iron in the violet and yellow-red regions from intensity 1 to 8 are given for each intensity in the following table. In the upper section the displacements are as measured. In the lower section, when reduced to a common wave-length, λ 5000.

TABLE II

DISPLACEMENTS AND WAVE-LENGTH

Region	Mean λ	Intensity								Mean
		1	2	3	4	5	6	7	8	
Violet	4017	0.022	0.020	0.014	0.014	0.013	0.011	0.008	0.006	0.014 Å.
Yellow-red	6121	.032	.030	.032	.024	.028	.024	.019	.016	.026
Violet	4017	.026	.024	.019	.018	.017	.013	.011	.008	.017 Å.
Yellow-red	6121	0.027	0.024	0.026	0.021	0.023	0.020	0.015	0.013	0.021

The means of the unreduced displacements are violet 0.014 Å., red 0.026 Å.; of the reduced displacements, 0.17 Å., and 0.021 Å., respectively—results that seem decisively in favor of an effect varying as the wave-length. The spectra of the two regions were of necessity photographed separately, and there was no over-lapping series of plates by which the relative displacements could be exactly determined. In each region the plates varied among themselves, due to slight changes in the position of the slit of the spectrograph in reference to the edge of the penumbra and to the fact that they do not always pertain to the same spot. In the means from a large number of plates, these accidental variations tend to neutralize each other. The violet region is represented by 34 plates and 81 lines, the yellow-red region, by 66 plates and 43 lines. In view of the probability that the effect of accidental variations is largely eliminated, the differences between the absolute displacements in the two regions may be considered to be fundamental and the decrease from 0.012 to 0.004 Å. in the mean difference when the displacements are reduced to a common wave-length indicates that the observed differences are due to the Doppler effect, and that we are dealing with real movements of gases in the reversing layer. The values used in the comparison were deduced from all the lines measured, and no account was taken of the effect arising from the different groups of iron lines or from the different spectral regions, other than that due to change in wave-length.

A fact equally striking is the systematic variation of the displacements with the intensities of the Fraunhofer lines. For lines of the intensities considered, the displacements progressively

decrease with the increase of line intensity. In Table III the mean displacements of 193 iron lines of intensities 1 to 8 are given under their respective intensities.

TABLE III

DISPLACEMENTS AND LINE INTENSITIES REDUCED TO λ 5000

Mean λ	Intensity								No Lines	Mean Interval
	1	2	3	4	5	6	7	8		
4017	0.026	0.024	0.019	0.018	0.017	0.013	0.011	0.008	81	0.003 Å.
4992	0.030	0.026	0.026	0.025	0.018	0.016	0.006	0.007	69	0.003
6121	0.027	0.024	0.026	0.021	0.023	0.020	0.015	0.013	43	0.002
Wtd. mean	0.028	0.025	0.023	0.021	0.019	0.016	0.012	0.009	..	0.003
Vel. km/sec.	1.68	1.50	1.38	1.26	1.14	0.96	0.72	0.54	..	0.18

For these lines the wave-lengths are longer on the limb edge of the penumbra than on the center edge when the spot is between the center of the sun and the limb, and the flow of the gases is outward and tangential to the solar surface, and on the assumption that, on the whole, the weaker lines originate at the lower level the velocity outward increases with the depth.

Though the lines of a given intensity in a given spectral region originate at some mean depth, it is not probable that the same mean depth would be found when widely differing spectral regions are compared. In Table IV the residuals are given for the three regions included in the investigation. These are obtained by deducting the mean displacements from the displacement for each of the three regions.

The consistently negative residuals for the violet region and the positive residuals for the yellow-red region point to a lower level in the region of longer wave-length for the lines of the same intensity. The mean level of lines in the red is about two units of intensity lower than in the violet; lines of intensity 4 in the red region being then at the level of lines of intensity 2 in the violet, and similarly for lines of other intensities. Such a difference is the natural consequence of the scattering of light by small particles, which varies inversely as the fourth power of the wave-length. From this it would result that we see into the sun to a greater depth

in the red than in the violet. If this difference in level is taken into account when the displacements in the violet and yellow-red regions are compared after reduction to a common wave-length, the agreement is very close. In Table V the first intensity refers to the violet, the second to the yellow-red, so that the comparison

TABLE IV

RESIDUALS

Intensity	Violet λ 4000	Blue-Green λ 5000	Yellow-Red λ 6100
1	−0.0018	+0.0014	+0.0014
2	− .0008	+ .0019	+ .0005
3	− .0043	+ .0031	+ .0036
4	− .0030	+ .0039	− .0004
5	− .0025	− .0006	+ .0040
6	− .0033	− .0004	+ .0037
7	− .0010	− .0055	+ .0032
8	−0.0013	−0.0019	+0.0041
Mean	−0.0023	+0.0002	+0.0026

is now between lines at approximately the same levels. The means of the unreduced displacements are 0.016 Å. and 0.024 Å., of the reduced displacements 0.0195 Å. and 0.0197 Å., respectively. The sum of the differences violet minus yellow-red is −0.001 Å.

TABLE V

DISPLACEMENTS AND WAVE-LENGTHS

Comparisons between Lines at Same Levels

Intensities	1, 3	2, 4	3, 5	4, 6	5, 7	6, 8
Violet	0.026	0.024	0.019	0.018	0.017	0.013
Yellow-red	0.026	0.021	0.023	0.020	0.015	0.013
Difference	0.000	+0.003	−0.004	−0.002	+0.002	0.000

For lines of intensities exceeding 10, the displacements are small or negative and then increase numerically with the elevation. The data are summarized in Table VI.

The negative sign indicates that the wave-lengths of the corresponding lines are shorter on the limb edge of the penumbra than

on the edge toward the center of the sun's image, and therefore denotes an inflow of the gases at the level of these lines with velocities increasing with the elevation.

TABLE VI

DISPLACEMENTS OF STRONG LINES (λ 5000)

Element	*Mg*	*Si*	*Al*	*Sr*	*Ca* (λ 4227)	H (H_β)
Intensity	10	12	15–20	8	20	40
Displacement	+0.002	0.000	0.000	−0.002	−0.002	−0.005
Vel. km/sec	+0.12	0.00	0.00	−0.12	−0.12	−0.30

Element	*Na* (D_1, D_2)	*Mg* (b_2, b_1)	H (H_γ)	*Ca* (H_2, K_2)	H (H_α)	*Ca* (H_1, K_1)
Intensity	20–30	20–30	20	.....	40	.....
Displacement	−0.006	−0.012	−0.033	−0.044	−0.050	−0.063
Vel. km/sec	−0.36	−0.72	−1.98	−2.64	−3.00	−3.78

The series of displacements in the case of the iron lines when arranged according to the intensities forms a practical and convenient scale for determining the relative levels in the solar atmosphere at which the lines of other elements are produced. Extending the series to include *Fe* 00 and *Fe* 15–40, which then covers the entire range of iron lines, we have the following iron scale:

TABLE VII

THE IRON SCALE (λ 5000)

Intensity	00	0	1	2	3	4	5	6	7	8	10	15–40
Displacements	0.034	0.030	0.028	0.025	0.023	0.021	0.019	0.016	0.012	0.009	0.004	0.000
Vel. km/sec	2.04	1.80	1.68	1.50	1.38	1.26	1.14	0.96	0.72	0.56	0.24	0.00

The extreme values at either end depend upon very few lines and are consequently of relatively low weight. On but one plate was it possible to measure the *Fe* lines of intensity 0 and 00. This gave the values 0.029 Å. and 0.036 Å. for the two intensities. The values found by extrapolation from the values 1–8 are 0.031 and 0.033 Å. The means of the observed and extrapolated values have been used to extend the scale. Three difficult iron lines,

intensities 15, 20, and 40, gave the value 0.000 as a mean of closely agreeing values. The displacements and the corresponding velocities are, throughout, the relative values for the two edges and are to be divided by two, so that the maximum velocity of outflow indicated by the means is 1 km per second. The maximum outward velocity observed in the case of any line was 2.2 km per second.

RADIAL VELOCITIES AND THE SOLAR VORTEX

When the velocities radial to the vortex axis and tangential to the solar surface are plotted as abscissae with elevations above the continuous spectrum background as ordinates upon any convenient scale, a very striking distribution is shown. Such a vertical section through the axis of the vortex is given in Fig. 2. In the lower portion representing the effective levels in the reversing layer, the velocities are mainly those given by the iron lines; in the upper portion, which refers to the chromosphere, the identification of the lines is given in connection with the plotted velocities. The ordinates are entirely arbitrary and are only meant to indicate the increasing velocities of inflow with increasing elevation above the region of velocity-inversion and the increasing velocities of outflow as the depth increases below this level. At the right are given some elevations taken from Jewell's table of which he says: "I have tried to give a fair and conservative estimate determined from several plates."[1] In the diagram are also given some preliminary and fragmentary results obtained in the course of an extended investigation of pressures in the solar atmosphere now being carried on, but upon which considerable reliance can be placed when it is a question of the variation of pressure with depth.

The distribution of the plotted velocities might lead one at first to consider them as representing the inflow and outflow of the gases in the case of an actual vortex. This comes partly from the apparent symmetry of the diagram, but the scale is very different above and below the level of inversion. The lower portion is some 3500 km thick while the upper is over 20,000 km in thickness.

[1] *Publications of the U.S. Naval Observatory*, **4**, Appendix I, 299–307.

so that the actual height of the upper portion is several times that of the lower.

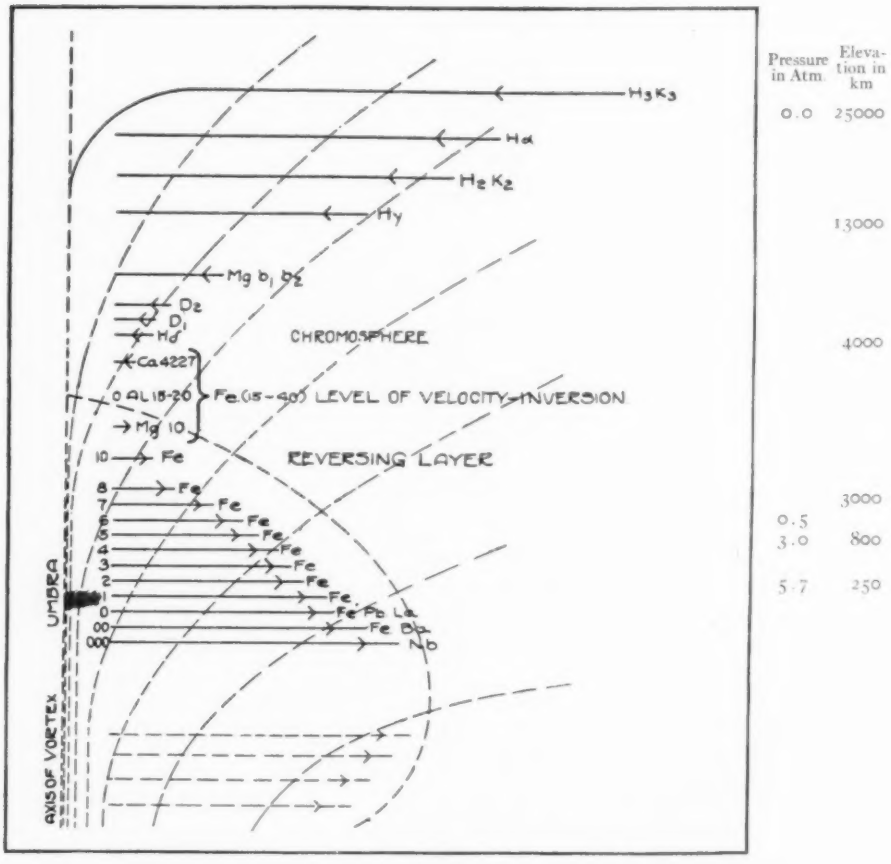


FIG. 2.—Vertical section of reversing layer and chromosphere showing the distribution of radial velocities in sun-spots. The lengths of the solid lines are proportional to the radial displacements of the corresponding Fraunhofer lines. The arrows indicate the direction of flow. The rounded head of the cyclonic disturbance is suggested by the broken-line curve enveloping the outward velocities. The broken lines with arrows refer to possible velocities below the accessible levels. The lines of force of the magnetic field are indicated in the usual way.

There are three lines of argument militating against the view that these velocities form the velocity system of an actual vortex.

In the first place, the composition of the material flowing outward in the lower portion is very complex, containing, as will be shown in a later paper, at least 27 elements—in fact, all elements the lines of which have been investigated in this paper—while the inflowing material is calcium, hydrogen, magnesium, sodium, and probably some of the higher level vapors of iron, aluminium, and strontium. It will be noticed that the level of velocity inversion is about where the customary division is made between the chromosphere and the reversing layer. Secondly, the masses involved in the inflow and outflow are quite different. An approximate value for the mass which flows across the boundary into the spot from the chromosphere may be found as follows. The velocity in this region decreases with increase of the density of the inflowing gases, so that the center of the mass of the inflowing material is located in the level where the velocity is low. For an approximation, the level may be assumed to be that of magnesium, b_1, b_2, where the velocity of inflow is 0.36 km per second. The pressure is very low at the level of this velocity, perhaps 0.1 terrestrial atmosphere, since in the upper reversing layer it is much less than 1 atmosphere and rapidly decreases upward. The mass resting upon an area of 1 sq. cm $= m = P/G = 100/27.6 = 3.6$ grams, where G is the solar gravitation constant.

The mean radius of the penumbrae of the spots under investigation is 11,250 km, so that the velocities found are the velocities normal to the surface of a cylinder of this radius. The quantity of material crossing the boundary in one second may be found by considering a shell of the given radius whose thickness is numerically equal to the velocity per second inward across the boundary, and upon the cross-section of which the surface density is the mass of the homogeneous atmosphere per square centimeter, that is, $2\pi Rm\Delta R$. In the present case $R = 11{,}250$ km, $\Delta R = 0.36$ km, and $m = 3.6$ grams. The mass so calculated is $29\pi \times 10^{13}$ grams.

In like manner an approximate value of the mass that flows across the boundary outward into the reversing layer may be found. The velocity in the reversing layer increases with the increase of density, and both increase rapidly with depth, so that the center of mass of the outflowing material is in the level where

both velocity and density are high. It may be assumed to be at the level of *Fe* 00 where the velocity is 1 km per second. From the rapid increase of pressure with depth the pressure may be assumed as 10 terrestrial atmospheres. The mass of the reversing layer resting upon an area of 1 sq. cm is then $360-3.6=356$ grams, and the mass moving outward per second is $8\pi 10^{15}$ grams, and the ratio of the inflowing to outflowing mass is 276.

The third reason is based upon the energy crossing the boundaries above and below the level of inversion, in the chromosphere and in the reversing layer respectively. The ratio MV^2 (reversing layer)/MV^2 (chromosophere) reaches the approximate value 2000. It is true that these are approximate values and only roughly approximate, but from the order of the ratios it is evident that the outflow into the reversing layer is not fed by the inflow from the high level, and that both the mass and the energy supplied from above are only small fractions of that flowing out below, while in a true vortex there is an equilibrium between the two activities.

In the terrestrial cyclone and especially in the types represented by the tornado, hurricane, and water-spout, it is known that in the upper portion the air is moving outward. Moore, in describing the hurricane, says:

> In the cirrus cloud level, 10,000 to 12,000 m. above the sea, the clouds are observed to move rapidly outward in all directions. The outward moving clouds represent the radial velocities in the upper levels of the dumb-bell vortex while the inner wind velocities found on the sea-level occur in the plane which truncates the vortex at some distance above the theoretical lower boundary plane. . . . . The radial velocity diminishes up to the middle plane and then increases outward; the tangential velocity increases up to the middle plane and then gradually diminishes. Near the center the centrifugal force is so great, on account of the rapid rotation of the air in the inner rings, that there is practically a calm central core, something like 20 or 30 miles in diameter.[1]

The outward velocities in the reversing layer at the outer boundaries of the penumbrae of sun-spots may then, with great probability, be referred to a low-lying vortex, since the outflow is not supplied from the higher levels. In the upper part of a

[1] *Descriptive Meteorology*, pp. 162–163.

dumb-bell or trumpet-shaped vortex the radial velocities increase with higher levels and in the theoretical discussion the radial velocities approach infinite limits and become asymptotic to the plane of reference. In the reversing layer the velocities increase with the depth, and it is true that the radial velocities outward in cyclones increase with height above the middle plane, but in the nature of things these outward movements of the air after reaching a maximum must decrease with greater height, by propagating themselves into and by entraining the overlying air, so that the region of disturbance would be dome-shaped above and the surface of zero radial velocity would have the dumb-bell form. This spreading and rounded head is characteristic of the whirling columns of steam, smoke, and ashes that rise from volcanoes and great furnace stacks.

The complete radial velocity system in the upper section of a solar vortex is indicated in the diagram by including the dotted abscissae, and the section of the surface of zero radial velocity by the enveloping curve. From this point of view the level reached by the spectrograph is still above the region of outwardly decreasing velocities, and such a region is as yet inaccessible to the spectroscope directly, since the level reached by this method of sounding the solar atmosphere cannot be deeper than the level at which the weakest Fraunhofer lines originate. Iron and vanadium lines of intensity ∞ still indicate by their displacements outward velocities increasing with the depth and it is not probable that lines of 2 intensities less, the weakest in Rowland's table, will reach the level of decreasing velocities. In the levels accessible to spectroscopic investigations the tangential velocities in the vortex have disappeared; their maximum value would occur at far lower levels. The same is true in the case of the vertical component, as both reach their maximum values in the middle plane of the vortex. This explains the failure to find definite indications of such velocities from displacements due to the Doppler effect. It is possible that by employing the lines of lowest level evidences of such velocities may be found in occasional spots.

The inflow of the chromospheric gases seems to follow, in part, at least, from the general downward movement of these gases.

This settling effect was shown for magnesium and sodium by Perot and Lindstreedt,[1] and for calcium in my paper on the general circulation of calcium.[2] The temperature in or immediately above the umbrae of spots is lower than in the surroundings, and this would produce in the overlying gases an added tendency to fall. As a result of one or both effects a downward flow would set in over the umbrae. Such an effect is indicated by the early observations of Respighi, who states as follows the results deduced from his observations made upon the border of the sun's disk:

1. In the neighborhood of the spots the chromosphere (*strato rosato*) is rather low, quite regular, and intensely bright.

2. Upon the exact locality of a spot or rather over its nucleus the chromosphere is generally very low and sometimes totally wanting.[3]

The downflowing gases would be caught in the current of the outflowing vapors in the upper portion of the vortex, and carried outward into the upper reversing layer, and the circulation once started would tend to continue. As in the case of fluids flowing into a sink, a whirl would in general be produced. The direction of this whirl would have no necessary hydrodynamical connection with the direction of rotation in the underlying vortex, since the tangential motion in the vortex ceases before reaching the lower reversing layer, and therefore is not propagated into the overlying region as the radial motions are. It is probably this upper whirl that has given the indications of inward flow and of vortex motion in spots that the visual observations, such as those of Secchi, occasionally show, and very probably the spectroscopic evidences of inflow and rotation of the high-level calcium vapor shown by my observations[4] refer to this pseudo-vortex. These observations, when considered from this point of view, are more easily interpreted. The wave-length of K_3 was measured at the center and over flocculi, penumbrae, and umbrae. The most striking feature of these

[1] *Comptes rendus*, **152**, 1367, 1911; **154**, 326, 1912.

[2] *Contributions from the Mount Wilson Solar Observatory*, No. 48; *Astrophysical Journal*, **32**, 36–82, 1910.

[3] *American Journal of Science*, 3d Series, **1**, 1871.

[4] *Contributions from the Mount Wilson Solar Observatory*, No. 54; *Astrophysical Journal*, **34**, 57–78, 131–153, 1911.

measurements is the remarkable agreement of the means for the separate regions with the general mean from 500 observations, which indicates a downward movement of approximately 1.1 km per second. A downward movement of the calcium vapor showed at all times in 88 per cent of the spots, varying in velocity from 0.68 km to 2.2 km with a general mean of 1.3 km per second. Four spots showed a motion of rotation of inflowing vapor with radial components for K_2 and K_3 of 1.24 km and 2.00 km per second, and tangential components of 0.98 km and 1.6 km per second, respectively. The small amount by which the downward velocity over spots exceeded that over the general surface, the fact that some spots gave no spectroscopic evidence of descent over the umbrae, and the small number of spots that showed vortex motion seemed surprising from the point of view that the observations refer to the real vortex, and especially in view of the fact that every spot is the seat of a magnetic field, as the results from Mr. Hale's discovery of the Zeeman effect in sun-spot spectra have shown. And there appears to be no other explanation than that the field is due to the existence of a vortex. But if a vortex, why do the surface indications so frequently fail to give evidence of it through spectroscopically observed displacements of the Fraunhofer lines or the vortical structure of the H_α flocculi in spectroheliograms? More rarely still do the conspicuous H_2 flocculi show any radial structure. The difficulties are in great measure removed by considering these as secondary and superficial effects depending upon elevation, the properties of the elements, and the field at these great distances from the underlying vortex. The cool region above the umbra acts as a sink into which the chromospheric vapors descend with or without the formation of a whirl, and from which they are discharged into the upper reversing layer. The whirl when formed may bear no relation to the direction of rotation, and only a very loose relation to the intensity of the underlying vortex. The conditions favoring the production of vortex structure in the inflowing gases are quite different at the levels of the H_α and H_2 flocculi. These levels are widely separated, the level of the H_α flocculi is probably some thousands of kilometers above the level of the H_2 flocculi, which are not far from the level of the upper

reversing layer. At the level of the H_α flocculi the conditions are: inward velocity high, magnetic field strong, inertia of ions small; and at the level of the H_2 flocculi the conditions are: inward velocity low, magnetic field stronger, inertia of ions large.

From an electrodynamic point of view, a view suggested by Professor Störmer, the high inward velocity of the hydrogen, due mainly to the general inflow, and the small inertia of the hydrogen ions are conditions favorable to the production of stream-line structure in the H_α flocculi by a magnetic field which may act mainly as a directing force upon the inward moving ions. At the level of the H_2 flocculi the relatively quiescent state of the gases and the great inertia of the calcium ions, the *Ca*-ion having forty times the mass of the *H*-ion, are conditions very unfavorable to the formation of stream lines at this level. The force exerted by the field upon the ions varies directly as their velocity which, at this level, is very small, since the H_2 flocculi are not far above the level of velocity inversion, and the velocity produced by the field varies inversely as the mass of the ion.

From a hydrodynamic point of view also the conditions are favorable to the production of stream lines in the H_α flocculi, as the hydrogen is flowing into the spot, but at the level of the H_2 flocculi the motion is small or nil, and stream lines are absent because there is little or no flow into the spot at this level. Bearing upon the quiescent condition of the gases producing the H_2 flocculi are some data I obtained when looking for evidence of vertical motion in the bright calcium vapor over the flocculi around spots. It had been assumed in the literature of the subject that this bright material was rising. The wave-lengths of the bright K_2 line over various regions when on the meridian were found to be as follows:[1]

Over general surface	3933.641
Over flocculi	.664
Over penumbrae	.665
Over umbrae	.682
In the arc	.667

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 54; *Astrophysical Journal*, **34**, 57–78, 131–153, 1911.

There is a rise of the calcium vapor over the general surface and a descent over the umbrae of 1.97 km and 1.3 km per second respectively, but over the flocculi and penumbrae an almost stationary condition obtains.

The occasional occurrence of vortical motion of the calcium vapor and the stream-line structure of the hydrogen flocculi may be coincident with the presence in spots of especially strong magnetic fields. A comparison of the field strength in spots showing these phenomena with that in spots in which these phenomena are absent throws some light upon this interesting question.

In the "Summary of the Results of the Study of the Mount Wilson Photographs of Sun-Spot Spectra,"[1] Mr. Adams gives a list of lines for which the separations in the spot spectra have been measured. The separations given by the lines upon Plate T 219 are given in a separate column, as they were distinctly greater than for the other spots. The Greenwich numbers for the spots are 6393, 6441, 6511, 6577. From nine lines which were measured as doublets upon all the plates the ratio of the field given by T 219 to the mean of the other plates is 1.3. The umbra of this spot was very black and large and the total magnetic flux was much greater than for either of the other spots. It was 2.5 times the mean for the other spot, when the areas of the umbrae and field intensities are both taken into consideration. The spot is No. 6577, a spot remarkable for its numerous returns, as it persisted during seven rotations of the sun. Of this spot I said in my paper on the "Motion and Condition of Calcium Vapor over Spots and Other Special Regions": "In the case of Spot 6577, when it was near the west limb, the north edge of the penumbra gave the shorter wave-length. When it appeared at the east limb as 6592 the south edge gave the shorter wave-length."[2] In both cases the rotation of the calcium vapor was clockwise. The H_α spectroheliogram shows marked radial structure of the hydrogen flocculi. Spot 6441 was next in size to Spot 6577, and showed hydrogen structure and at times great

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 40; *Astrophysical Journal*, **30**, 86–126, 1909.

[2] *Contributions from the Mount Wilson Solar Observatory*, No. 54; *Astrophysical Journal*, **34**, 57–78, 131–153, 1911.

activity. It was with this spot that I obtained the series of exposures showing a dark hydrogen flocculus being drawn into the spot. Six of these exposures are shown in Plates XXXVII, XXXVIII, XXXIX, of Mr. Hale's original paper on the solar vortices.[1] Spot 6393 showed no definite structure on the H_α spectroheliograms, but large bright eruptive areas following in the train of the spot. Spot 6511 gave no definite structure on an excellent plate that showed remarkably interesting structure about other spots on the sun's disk at the same time.

In the type of vortex in which the data of the present paper seem to find their interpretation, there is an enormous flux of energy from the vortex into and below the lower reversing layer. The mechanical energy of motion is rapidly transformed into other forms, as the velocity decreases rapidly with distance. The question of how rapidly will be taken up in a later investigation. The form and distribution of this energy in the surrounding region is another interesting question. In the umbrae of sun-spots we now recognize the presence of hydrides and oxides, as shown by the investigations of Fowler, Hale, Adams, and Olmsted. Owing to the low temperature in spots, it is possible that these compounds undergo condensation also. They will be carried with the general flow outward into the reversing layer where decomposition will take place at the expense of a part at least of the energy of the moving gases. But the greater part of this energy will be available for raising the temperature of these low-lying regions, and not only will the temperature be raised, but there will probably be a heaping-up of very hot material around the spot, which would explain the presence and the formation of the faculae. Such a piling-up of air around the cyclone center is evidenced by the high barometer around the center of disturbance.[2] Secchi's sketch of a spot and faculae, when near the limb on March 4, 1866, is suggestive of such a heaping-up of hot material around a spot. In my paper on the "Motion and Condition of Calcium over Special Regions"

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 26; *Astrophysical Journal*, **28**, 100, 1908.

[2] Reye, *Die Wirbelstürme, Tornados, und Wettersäulen in der Erd-Atmosphäre*, p. 135.

I was led to infer in the explanation of the character of the H_2 spectroheliograms at different levels that the faculae may be considered as regions from which a disturbance capable of increasing their emissive power is propagated into the overlying gases, and that these regions may be of higher temperature absolutely, or apparently so from their being elevated above a portion of the surrounding vapor, and that there is probably a piling-up of calcium vapor over the faculae.[1] The result of the flux of material and energy outward from the spot would be to produce both of these effects, and the enormously increased emission on the part of the calcium vapor producing the bright H_2 and K_2 components would be caused by the high temperature prevailing around the spot. The relative emissive power of the H and K lines increases rapidly with temperature, as King has shown.[2] The intensely bright and quiet chromospheric layer observed near spots by Respighi may be referred to the high temperature of the region surrounding spots.

The measurement of the line displacements given in Table I has been made by Miss Ware. I wish to express my appreciation of the patience and skill required in the long series of measurements and of her interest in the progress of the work.

SUMMARY

1. The observations reported in the present paper are in entire accord with Mr. Evershed's hypothesis that the displacements considered are due to a movement of the solar vapors tangential to the solar surface and radial to the axis of the spot vortex.

2. The proportionality between the displacements and wavelengths shows that the phenomenon is due to the Doppler effect and that we are dealing with an actual flow of the material of the reversing layer out of spots and of the chromospheric material into spots.

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 54, 40; *Astrophysical Journal*, **34**, 148, 1911.

[2] *Contributions from the Mount Solar Observatory*, No. 32; *Astrophysical Journal*, **28**, 389, 1908.

3. The increase of displacements indicating an outward flow with the decrease in the intensity of the lines of the reversing layer and the increase of the displacements indicating an inward flow with increasing intensity of the high-level lines of the chromosphere find their explanation in differences of level. The outward velocities increase with distance below a neutral level, the inward velocities increase with distance above this neutral level or the level of velocity inversion.

4. The vertical distribution of the velocities shows at high levels an inflow into spots and at low levels an outflow. A consideration of the quality and the quantity of the material and of the amount of energy involved in the two movements indicates that they do not of themselves form a vortex system.

5. The type of vortex indicated is that of the terrestrial tornado or hurricane. There is a whirling upward rush of material from the interior of the sun, which spreads out radially with rapidly decreasing velocity, tangential to the solar surface, and entrains with it the gases of the reversing layer. The actual vortex is deep-seated, the outflow into the reversing layer being a portion of the upper part of it, the inflow from the chromosphere being a secondary effect, a superficial indication of the underlying vortex in which the magnetic field originates.

6. The secondary phenomenon shows sometimes vortex motion of the high-level calcium vapor, visible evidences of vortex movements, and stream-line structure of the H_α flocculi, depending upon the strength of the magnetic field and the rotational energy of the underlying vortex.

7. The absence of stream-line structure in the H_2 flocculi follows from the quiescent state of the calcium vapor producing these flocculi. This shows no vertical motion, and the flocculi are near the level of zero velocity along the solar surface.

8. The flux of gases into and below the lower portion of the reversing layer would cause a piling-up of material, the temperature of which would be raised by the rapid transformation of mechanical energy into heat, and the increased emission of the calcium vapor would then be a temperature effect.

9. When the displacements of lines in the red and violet of

equal solar intensities are compared, the lines in the violet show the smaller displacements and therefore originate at higher levels, a consequence of the scattering of light.

10. The displacements of the iron lines arranged in the order of intensities from ∞ to 10 form a regular descending scale for determining the relative levels in the solar atmosphere at which the lines of like intensities of other elements have their origin.

MOUNT WILSON SOLAR OBSERVATORY
December 23, 1912

CIRCULATION IN THE SOLAR ATMOSPHERE AS INDICATED BY PROMINENCES

SECOND PAPER

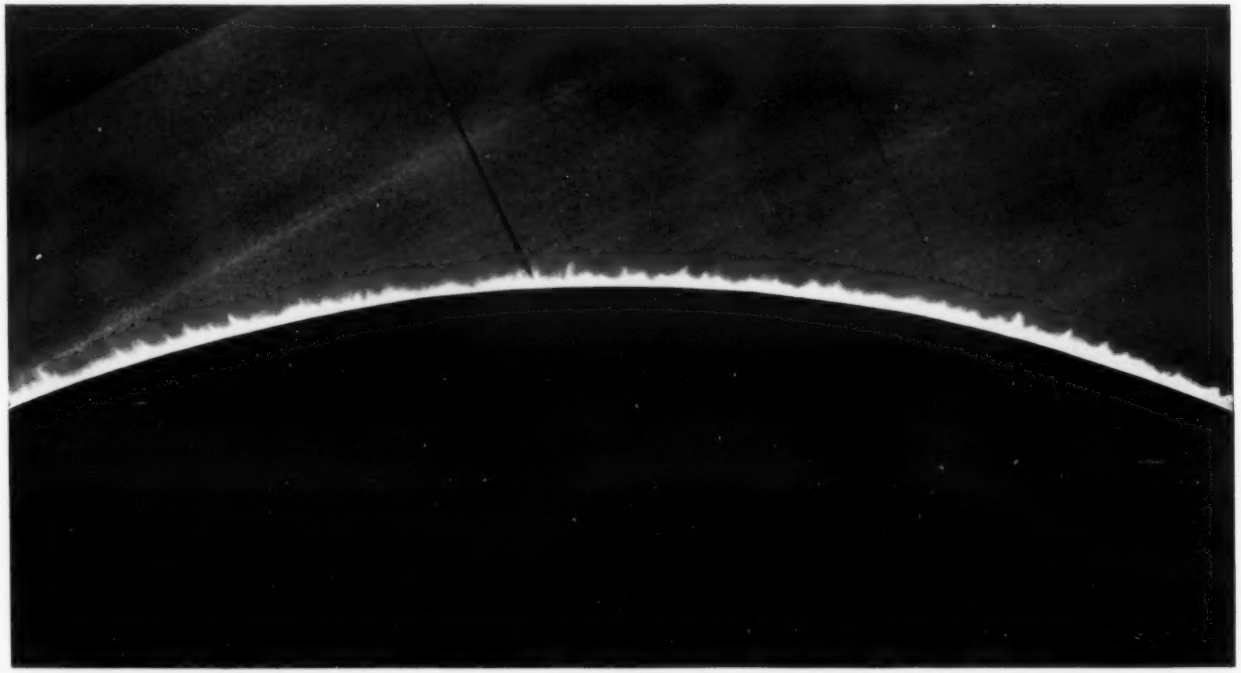
By FREDERICK SLOCUM

In the *Astrophysical Journal*, **33**, 108, 1911, I presented a preliminary paper on the above subject. The investigation discussed therein was suggested by the fact that, in the course of the study of the solar prominences photographed with the Rumford spectroheliograph of the Yerkes Observatory, so many of the prominences presented the appearance of being driven to one side by a horizontal current that it seemed worth while to make a special study of these cases, to see if they might not throw some light upon the circulation of the sun's atmosphere.

Illustrations and descriptions of the different types of prominences used as directional in that former, and also in the present investigation, were published in connection with the above-mentioned paper. In that investigation no discrimination was made between high and low prominences, so the conclusions pertain to the average height of all, namely 0.′7 or 30,000 km. In many cases, however, low and high prominences in the same vicinity appear to be moving in opposite directions, which might indicate the existence of an upper and a lower current. In the present investigation, therefore, the prominences have been tabulated according to height.

I have recently brought the examination of the prominence plates down to the end of the year 1912. Upon all of these plates I have also studied carefully the structure of the chromosphere. This has frequently been described as resembling grain blown by the wind, and I hoped to get from this the prevailing current at the lowest level. I found, however, but few cases that showed a general tendency in one direction. Plate XIII shows a portion of the chromosphere as photographed in the light of calcium with the spectroheliograph. Much of the fine detail is lost in the repro-

PLATE XIII



SPECTROHELIOGRAM OF CHROMOSPHERE, MAY 23, 1912
Scale: 1 mm = 3060 km

duction, but it can be seen that the directions of the spikes and jets seem to be wholly at random.

Forty-six hundred prominences have been examined, of which over 1500 indicate direction. The data have been tabulated according to the limiting latitudes of each prominence, the direction of apparent motion, the maximum height, and type. The values were summarized by counting the number of directional prominences in each five-degree zone of latitude from the north to the south pole. When a prominence extended over two or more zones it was counted in each zone. The results were summed and the percentage of poleward direction computed.

TABLE I

Latitude	Northern Hemisphere			Southern Hemisphere		
	Number		Percentage Poleward	Number		Percentage Poleward
	−	+		−	+	
80–85	7	5	42	11	14	56
75–80	16	5	24	22	19	46
70–75	21	10	32	26	22	46
65–70	24	11	31	29	21	42
60–65	48	11	19	34	28	45
55–60	53	29	35	36	31	46
50–55	44	37	46	40	49	55
45–50	35	48	58	49	65	57
40–45	53	65	55	46	61	57
35–40	53	70	57	52	54	51
30–35	52	85	62	55	64	54
25–30	50	62	55	56	62	53
20–25	58	61	51	67	61	48
15–20	58	64	52	60	67	53
10–15	51	51	50	59	62	51
5–10	52	42	45	53	59	53
0– 5	50	39	44	39	60	61

+ indicates direction toward the pole.
− indicates direction from the pole.

Table I shows the tabulation for all prominences without regard to height. Similar tables were made for prominences between various limits of height. The minus sign indicates direction toward the equator, the plus sign toward the pole. In the zone from 60° to 65° of north latitude, for example, there were 48 cases of apparent motion toward the equator and 11 cases of motion toward the pole, giving 19 per cent of poleward motion.

that is, a decided tendency toward the equator. Again between 30° and 35° north latitude there were 85 cases toward the pole

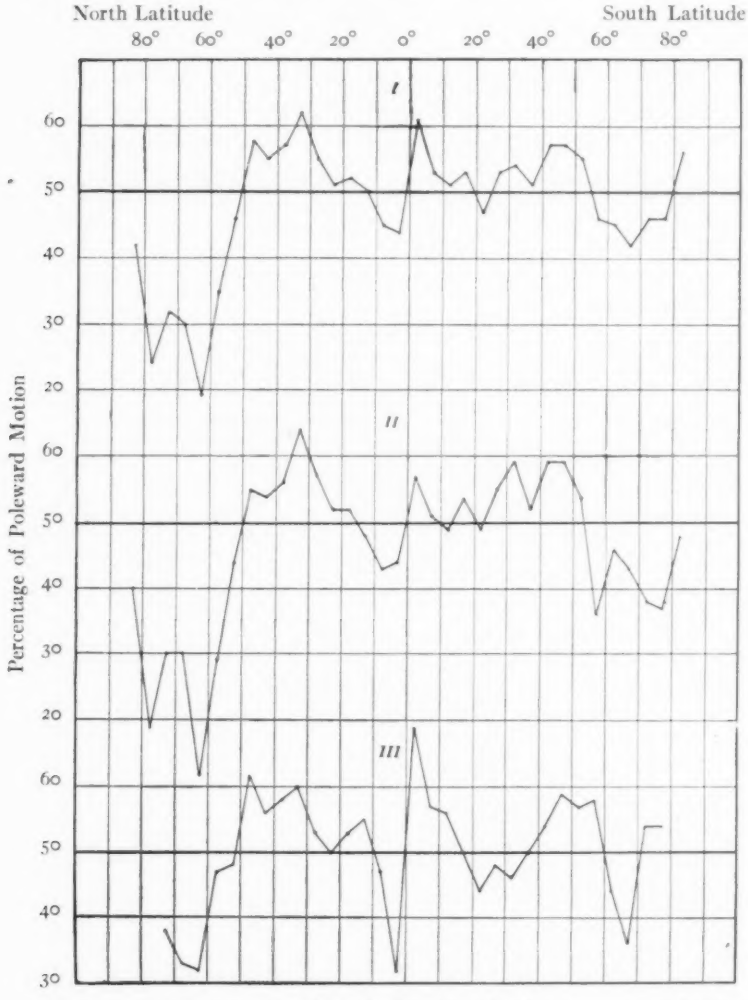


FIG. 1.—Percentage of poleward direction of solar currents as indicated by prominences.

I All prominences II Low prominences III High prominences

against 52 toward the equator, giving a poleward percentage of 62 per cent. A percentage of less than 50 per cent means a tendency

toward the equator, greater than 50 per cent toward the pole. The accompanying diagram shows graphically the results given in the table and also results for similar tabulations for high and low prominences, that is, for prominences less than 1′.0, or 43,000 km in height and for those from 1′.0, up.

The abscissas are solar latitudes; the ordinates, percentage of poleward motion. The X-axis represents percentage 50. Points above the X-axis indicate a motion toward the pole, below the axis, toward the equator.

Curve I, which is based upon 1524 prominences, confirms the facts brought out in the former paper, showing maxima in middle latitudes and minima in high latitudes. Moreover, the other two curves show practically the same phenomena, which signifies that the prevailing tendencies noted pertain to the whole realm occupied by prominences. If there is a counter-current, it must be below the chromosphere or above the prominences.

All three curves also show a minimum between 0° and +10° and a maximum between 0° and −10°, which, if real, would signify a current right across the equator from 10° north to 10° south latitude. This would be somewhat analogous to the southeast trade winds in the Atlantic Ocean in July, which prevail from latitude 15° south to latitude 8° or 10° north.

The conclusions from this investigation are given in the following summary:

1. Many prominences, by their shapes or movements, seem to indicate the existence of a horizontal current in the solar atmosphere.

2. This current may have opposite directions at different altitudes in the same locality.

3. It may change its direction, just as the wind changes upon the earth. (See *Astrophysical Journal*, **35**, 301, 1912, Plates XV, XVI, and XVII.)

4. In middle latitudes the average tendency for movement is toward the poles.

5. In high latitudes the average tendency for movement is toward the equator.

6. This tendency is much more marked in the northern than in the southern hemisphere.

7. From latitude 10° north to 10° south the average tendency is from north to south directly across the equator.

8. The prevailing directions mentioned above are the same for prominences of all heights.

9. Upon a rotating sphere the circulation is undoubtedly spiral. The observations used in the present investigation take account only of the north and south components. The east and west components may eventually be added by an extended series of radial velocity measures of prominences.

10. Observations upon prominences within 5° or 10° of the poles are unreliable for determining direction of motion, as a prominence approaching the pole spirally may project so as to be moving apparently away from the pole.

YERKES OBSERVATORY
January 23, 1913

THE DETERMINATION OF AQUEOUS VAPOR ABOVE MOUNT WILSON[1]

By F. E. FOWLE

This paper gives the amounts of aqueous vapor above Mount Wilson, California, on certain days of the years 1910 and 1911 as determined by the method developed in the article entitled "The Spectroscopic Determination of Aqueous Vapor" in the *Astrophysical Journal* for April of last year.[2] A comparison is then made between the values thus determined and those obtained from the formula developed by Hann, Humphreys, and others.

OBSERVATIONS

On Mount Wilson, as a part of the regular observations for the determinations of the intensity of the solar radiation, each clear morning during the summer months, energy-curves of the solar spectrum are taken as the sun rises higher and higher above the horizon. In these curves (bolographs), the presence of water-vapor in the path of the sun's rays causes several deep indentations, or bands, which are deeper the greater the amount of water-vapor. With a height of the energy-curve on either side of the bands of some 10 cm, the depth in the bands may range from 3 to 8 cm. These magnitudes are so great that far higher accuracy is here possible than in atmospheric aqueous-vapor determinations by ordinary photometric measures of the photographic spectra sometimes used.

Across the top of a band produced in a bolographic energy spectrum of the sun by the atmospheric water-vapor a line is drawn and the transmissibility is measured by the ratio of the ordinate at the bottom of the band to the corresponding ordinate of the line drawn across the top. The loss of energy due to the general absorption of the atmosphere is eliminated from this ratio, since

[1] Published by the permission of the Secretary of the Smithsonian Institution.

[2] *Astrophysical Journal*, **35**, 149, 1912.

it affects in equal proportion both the enumerator and the denominator.

The calibration in the laboratory at Washington of these ratios for the bands ϕ and ψ' with the equivalent amount of water-vapor necessary to produce them was discussed in detail in the earlier paper. The results for ψ' were the more accurate. In the solar-

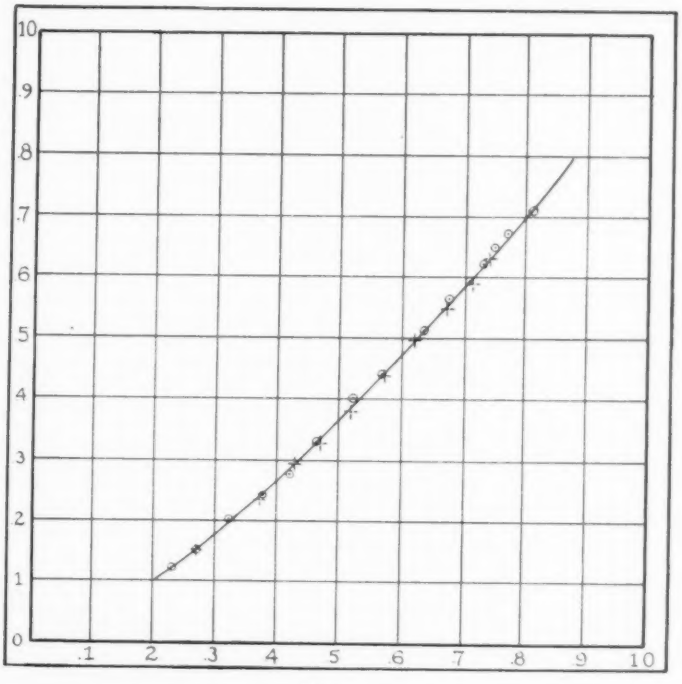


FIG. 1

Abscissae are transmissibilities for radiation by water-vapor in ρ ($\lambda = 0\mu.93$); ordinates are transmissibilities for radiation by water-vapor in ψ' ($\lambda = 1\mu.47$); circles represent 1910 data; crosses represent 1911 data.

spectrum work to be described the bands ρ, ϕ, ψ' were measured, ρ the most accurately,[1] ψ' the least accurately and only half as often as the others. In order to use the ρ ratios for the determination

[1] This difference in accuracy in laboratory and field observations of different bands is due to the very different distribution of energy in the solar prismatic spectrum from that in the Nernst-glower spectrum used in laboratory work.

of water-vapor, they must first be reduced to the corresponding ones for ψ' or ϕ. The full-line curve in Fig. 1 for this purpose is made by using the transmissibility in ρ as abscissae against those in ψ' as ordinates. The relation between the bands is so definite that the measures in ρ may at once be reduced to the corresponding values for ψ' and then by means of the calibration-curves (Fig. 7) of the earlier article, the amount of water-vapor corresponding to the depths of the three bands, ϕ, ψ', and ρ via ψ' is obtained.

REDUCTION OF OBSERVATIONS

The length of the path through the water-vapor in the atmosphere traversed by the solar beam is proportional to the secant of the zenith distance for the zenith distances used to within 1 per cent.[1] When the sun is in the zenith this length of path (air mass) is taken as unity. The observations are plotted as shown in Fig. 2, where the data of several days are treated, ranging from nearly the highest amount of absorbing vapor to nearly the lowest. As abscissae are used air masses, as ordinates the logarithms of the transmissibilities, since with these co-ordinates the resulting plots are nearly linear.[2]

From such plots were read for each day the transmissions at air masses 3.0 and 1.2, corresponding very closely to the beginning and to the end of a day's observations; the calibration plot (Fig. 7 of the earlier paper) was entered with these values and the corresponding amount of water in the form of vapor found; these values were then divided by the air masses, 3.0 and 1.2, respectively. The resulting water-vapor is stated as so much precipitable water, being the depth of liquid water which if in the form of vapor would be contained in the column of air of the same section reaching vertically to the limits of the atmosphere. This implies the same distribution of the vapor in successive atmospheric layers concentric with the earth for a vertical column as in the actually observed column which was not vertical.

[1] *Annals of the Astrophysical Observatory of the Smithsonian Institution*, **2**, 63.

[2] This is merely a convenient empirical device. The truly linear relation holds only for homogeneous rays.

These times for the determination of the vapor, namely, when the sun was at an altitude of 19° 27′ and 56° 26′, respectively (air

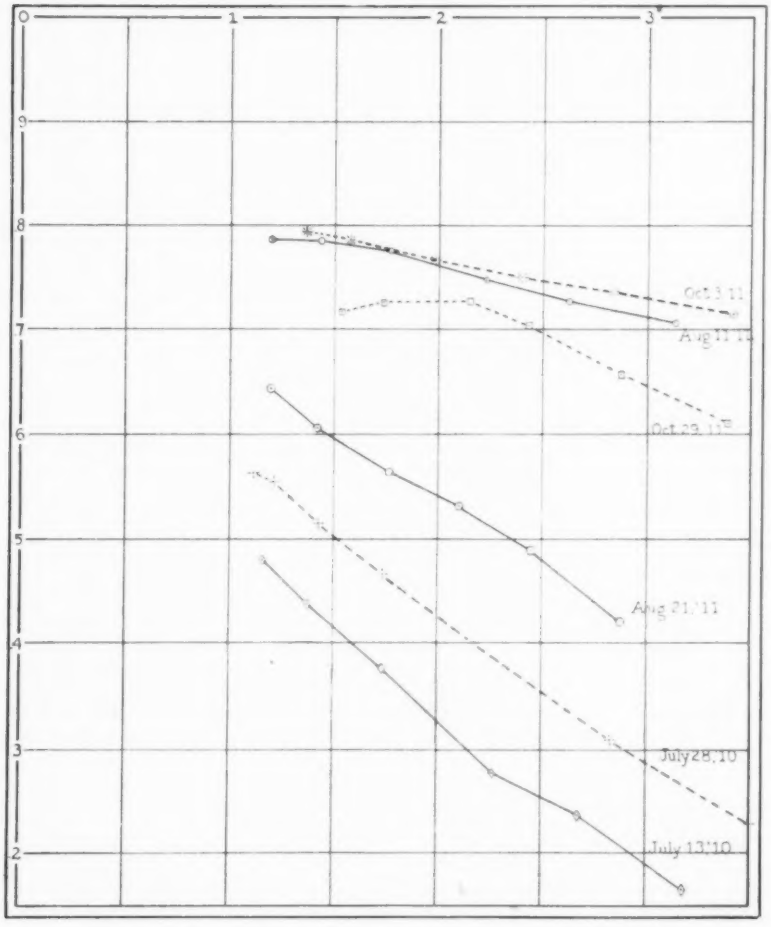


FIG. 2.—Illustrative of observations of water-vapor transmission and the method of reduction.

Abscissae are air masses (sec. zenith distance of the sun); ordinates are log transmission in Φ ($\lambda = 1^{\mu}.13$).

masses, 3.0 and 1.2), though perhaps ill chosen for meteorological purposes, were better adapted to the astrophysical purposes to which the data will finally be put. At latitude 34°13′ N. the

observations at air mass 3.0 correspond roughly to the following apparent times: May 1, 6^h54^m, June 1, 6^h37^m, July 1, 6^h34^m, August 1, 6^h47^m, September 1, 7^h14^m, October 1, 7^h47^m, November 1, 8^h25^m, all of the morning; for the air mass 1.2, roughly to 10^h A.M. The results thus obtained are given in the following table and the accompanying plot (Fig. 3). The table contains data only for 1910, merely to save space. The results for 1911 may be read from Fig. 3. Fuller data will be found in Volume **3** of the *Annals* of this observatory soon to be published.

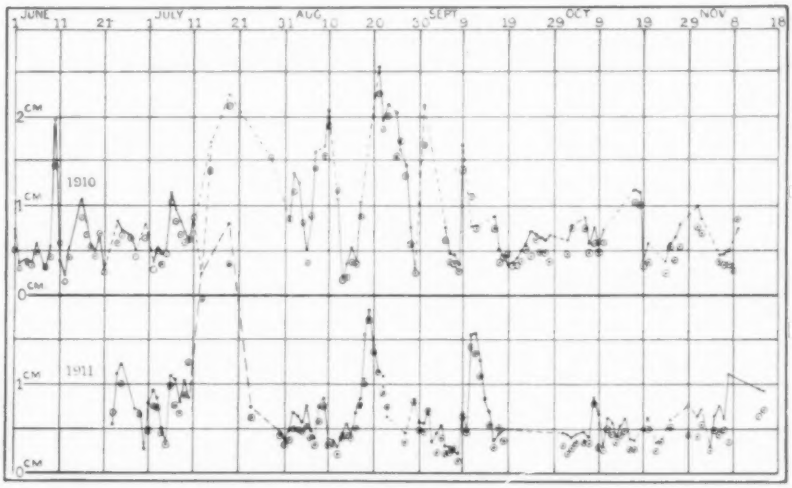


FIG. 3.—Aqueous vapor above Mount Wilson

Upper set is for 1910; lower for 1911; ordinates are depths of liquid water which, if in the form of vapor, would be contained in a column of the same section reaching to the limit of the atmosphere. Circles are the early morning values; lines connect the late morning points.

It may be noted that the values determined through ϕ are in general somewhat lower than those through ρ and ψ'. This may be because the slit correction (see earlier paper) is not complete. Again there is unfortunately a narrow absorption band very close to ϕ, due to the ultra-violet glass of which the prism of the spectroscope used at Mount Wilson is made, which may slightly influence the transmissibility for ϕ. The values for ψ' are on the average slightly lower than those for ρ. The calibration-curve (Fig. 1)

ATMOSPHERIC WATER-VAPOR, MOUNT WILSON, CALIFORNIA, 1910

Date 1910	Early Morning				Late Morning				Change	
	ρ	ϕ	ψ'	Mean *	ρ	ϕ	ψ'	Mean *	cm	Percentage
	cm	cm	cm	cm	cm	cm	cm	cm		
June 1	0.53	0.47	....	0.51	0.83	0.63	0.71	0.72	0.21	0.22
2	.33	.28	0.30	.30	.37	.33	.35	.35	.05	.17
4	.41	.34	.37	.37	.42	.36	.38	.39	.02	6
5	.38	.29	.34?	.33	.40	.24	....	.35	.02	6
6	.55	.43	.46	.48	.65	.55	.57	.59	.11	23
8	.32	.22	.38	.31	.37	.27	.26	.30	−.01	− 3
9	.46	.33	.50	.43	.56	.48	.62	.55	.12	28
10	1.84	1.07	1.40?	1.44	2.02	1.73	2.22	1.99	.55	38
11	0.71	0.50	0.56	0.59	0.42	0.32	....	0.39	−.20	−34
12	.17	.12	.14	.14	.21	.17	0.24	.21	.07	50
13	.44	.46	.37	.42	.55	.45	.56	.52	.10	24
16	1.00	.76	.86	.87	1.11	1.01	1.12	1.08	.21	24
17	0.76	.62	.70	.69	0.88	0.77	0.79	0.81	.12	18
18	.57	.49	.56	.54	.64	.51	.52	.56	.02	4
19	.48	.41	.40	.43	.54	.48	.45	.49	.06	14
20	.77	.66	.67	.70	.71	.57	.69	.66	−.04	− 6
21	.31	.23	.23	.26	.32	.23	....	.29	.03	12
24	.65	.54	.59	.59	.88	.73	.84	.82	.23	39
25	.71	.63	.64	.66	.78	.73	.64	.72	.06	10
27	.66	.57	....	.63	.71	.64	.67	.67	.04	6
28	.47	.39	.40	.42	.58	.48	.47	.51	.09	22
30	.69	.62	.61	.64	.84	.72	.82	.79	.15	24
July 2	.31	.27	.28	.29	.39	.36	.32	.36	.07	24
3	.56	.46	.48	.50	.58	.50	.51	.53	.03	6
4	.37	.31	.31	.33	.51	.44	.47	.47	.14	43
5	.57	.50	.34	.47	.57	.47	.47	.50	.03	6
6	1.21	....	.87	1.04	1.22	1.05	1.19	1.15	.11	11
7	0.92	.72	.78	0.81	1.02	0.91	0.95	0.96	.15	19
8	.72	.62	.71	.68	0.93	.75	.76	.81	.13	19
9	.65	.52	.61	.59	.75	.63	.71	.70	.11	19
10	.66	.57	.64	.62	.67	.54	.62	.61	−.01	− 1
11	.87	.83	....	.86	.87	.73	.89?	.83	−.03	− 4
15	1.42	1.19	1.53	1.38	1.82	1.58	1.74?	1.71	.33	24
19	2.19	....	2.10	2.14	2.38	1.97	2.45	2.27	.13	6
28	1.62	1.31	1.67	1.53	1.61	1.37	1.59	1.52	−.01	− 1
Aug. 1	0.83	0.74	0.92	0.83	0.95	0.77	0.73	0.82	−.01	− 1
2	1.18	.94	1.33	1.15	1.41	1.19	1.47	1.36	.21	18
3	....	....	....	....	1.31	1.07	1.35	1.24	....	....
4	0.83	.73	....	0.80	0.89	0.73	0.73?	0.78	−.02	− 2
5	.40	.32	0.35	.36	.54	.43	.58	.52	.16	45
6	.96	.80	.90	.89	.95	.73	.83	.84	−.05	− 6
7	1.51	1.26	1.45	1.41	1.67	1.42	1.70	1.60	.19	13
9	1.70	1.43	1.53	1.55	1.78	1.52	1.66	1.65	.10	6
10	1.91	....	....	1.91	2.17	1.89	2.22	2.09	.18	9
12	1.28	0.94?	....	1.17	1.06	0.96	1.19	1.07	−.10	− 9
13	0.19	.15	0.17	0.17	0.15	.17	....	0.16	−.01	− 6
14	.22	.17	.20	.20	.42	.27	0.36	.35	.15	75
15	.44	.33	.36	.38	.56	.46	.57	.53	.15	39
16	.36	.30	....	.34	.43	.27	....	.38	.04	12
17	0.94	.82	0.89	.88	1.12	0.98	0.98	1.03	0.15	17

* In taking the daily means, where ψ' has been lacking, double weight has been given ρ.

ATMOSPHERIC WATER-VAPOR, MOUNT WILSON, CALIFORNIA,
1910—*Continued*

Date 1910	Early Morning				Late Morning				Change	
	ρ	ϕ	ψ'	Mean *	ρ	ϕ	ψ'	Mean *	cm	Percentage
	cm	cm	cm	cm	cm	cm	cm	cm		
Aug. 21	....	....	2.27	2.27	2.83	2.34	2.53	2.57	.30	25
22	1.96	....	1.77	1.87	2.11	1.87	1.93	1.97	.10	5
23	2.09	....	1.93	2.01	2.24	1.98	2.20	2.14	.13	6
25	1.62	1.30	1.67	1.53	2.04	1.81	2.37?	2.07	.54	36
26	1.83	1.48	1.85	1.72	1.75	1.56	1.53	1.61	−.11	− 6
27	1.48	1.12	1.34	1.31	1.40	1.26	1.67	1.44	.13	10
28	0.63	0.49	0.60	0.57	0.77	0.63	0.84	0.75	.18	32
29	.26	.21	.22	.23	.32	.21	.30	.28	.05	22
Sept. 1	1.84	1.39	1.80	1.68	2.38	1.60	....	2.12	.44	26
5	0.63	0.53	0.67	0.61	0.78	0.61	.86?	0.75	.14	23
6	.40	.31	.39	.37	.52	.40	.53?	.48	.11	30
7	.37	.31	.37	.35	.42	.41	.54	.46	.11	32
8	.29	.21	.29	.26	.35	.35	.35?	.35	.09	35
9	1.64	1.21	1.33	1.39	1.86	1.34	....	1.69	.30	22
11	1.18	0.91	1.20	1.10	0.73	0.68	.89?	0.77	−.33	−30
12	0.72	.57	0.66	0.65	.75	.65	.91?	.77	.12	19
16	.80	.60	....	.73	.95	.73	....	.88	.15	21
17	.39	.32	.38	.36	.53	.43	.58	.51	.15	42
18	.44	.37	.43	.41	.48	.33	....	.43	.02	5
19	.50	.39	.49	.46	.37	.30	.39	.35	−.11	−24
20	.34	.27	....	.32	.38	.33	....	.36	.04	13
21	.34	.27	....	.32	.43	.37	....	.41	.09	28
22	.39	.34	.41	.38	.53	.44	.54	.50	.12	32
23	.58	.42	.57	.52	.61	.49	.65?	.58	.06	12
24	.47	.37	.46	.43	.77	.61	.75	.71	.28	66
25	.63	.51	.71	.62	.73	.62	.73	.69	.07	12
26	.50	.42	.53	.48	.66	.54	.73	.64	.16	33
27	.51	.42	.50	.48	.66	.47	.72	.62	.14	29
28	.41	.33	.40	.38	.75	.54	....	.68	.30	79
Oct. 2	.53	.42	.47	.47	.64	.56	.64	.61	.14	30
3	.83	.67	.74	.75	.92	.66	.76	.78	.03	4
6	.82	.65	.72	.73	.95	.78	.89	.87	.14	19
7	.51	.43	.49	.48	.62	.53	.61	.59	.11	23
8	.64	.53	.60	.59	.77	.71	.82	.77	.18	31
9	.58	.42	.48	.49	.63	.52	.60	.58	.09	19
10	.66	.54	.60	.60	.77	.68	.78	.74	.14	23
17	1.13	.93	1.04	1.03	1.43	.97	1.10	1.17	.14	14
18	1.14	.90	1.00	1.01	1.14	1.08	1.22	1.15	.14	14
19	0.37	.27	0.31	0.32	0.43	0.32	0.38	0.38	.06	19
20	.40	.32	.36	.36	.63	.53	.62	.59	.23	64
24	.27	.21	.24	.24	.38	.36	.43?	.39	.15	62
25	.60	.49	.55	.55	.61	.53	.61	.58	.03	6
26	.44	.34	.39	.39	.65	.63	.73	.67	.28	72
27	.59	.49	.55	.54	.88	.69	.80	.79	.25	46
31	.86	.67	.75	.76	1.11	.88	1.00	1.00	.24	32
Nov. 1	.79	.61	.68	.69	0.88	.77	0.88	0.84	.15	22
5	.46	.32	.36	.38	.49	.40	.47	.45	.07	19
6	.32	....	....	.32	.46	....	....	.46	.14	44
7	.36	.31	.36	.34	.50	.46	.53	.50	.16	47
8	.29	.23	.27	.26	.41	.28	.34	.34	.08	31
9	1.08	0.68	0.76	0.84	0.83	0.69	0.80	0.77	−.07	− 8

*In taking the daily means, where ψ' has been lacking, double weight has been given ρ.

MEAN MONTHLY ATMOSPHERIC VAPOR FOR CLEAR DAYS

	June	July	Aug.	Sept.	Oct.	Nov.
	cm	cm	cm	cm	cm	cm
Early morning, 1910	0.53	0.86	1.07	0.59	0.58	0.48
1911	.78*	.86	0.61	.56	.37	.49
Late morning, 1910	.62	.96	1.17	.70	.73	.56
1911	0.76*	0.99	0.72	0.63	0.52	0.74

*Few observations.

MEAN YEARLY ATMOSPHERIC VAPOR FOR CLEAR DAYS

	cm
Early morning, 1910	0.71
1911	.55
Late morning, 1910	.82
1911	0.69
General mean	0.69

CHANGE IN ATMOSPHERIC VAPOR DURING DAY OBSERVATIONS

Range	cm 0 to 0.05	cm 0.05 to 0.10	cm 0.10 to 0.15	cm 0.15 to 0.20	cm 0.20 to 0.30	cm above 0.30
1910	22 days	19 days	34 days	8 days	12 days	4 days
1911	14 "	21 "	21 "	8 "	9 "	7 "
Total	36 "	40 "	55 "	16 "	21 "	11 "

	cm
Average change, 1910	0.13
1911	.14
Average increase, 1910	.11
1911	0.12

was determined from 1910 and 1911 observations; 1911 data would show the reverse effect.

COMPARISON WITH DETERMINATIONS FROM SURFACE HUMIDITIES

The formula in most general use for the determination of the aqueous vapor present in the atmosphere from measures of the humidity at the surface of the earth by the readings of the "wet and dry" thermometers, or otherwise, is that due to Hann.[1] If Q_w

[1] Hann, *Lehrbuch der Meteorologie*, pp. 224–226.

is the depth in centimeters of the precipitable water in the atmosphere above a place, e_w the vapor pressure in centimeters of the water-vapor at the surface, and K a constant, then

$$Q_w = \text{precipitable water} = Ke_w.$$

Hann's value for K is 2.3.

Humphreys has recently[1] collected considerable further data from balloon and kite observations and considers that a somewhat smaller value of K, namely, 2.0, would be preferable for "clear days" such as would presumably be suitable for bolometric observations. Hann's constant was determined from observations on "all sorts of days."

The above values of K are for determinations from sea-level surface-of-the-earth data; for the elevation of Mount Wilson (1.73 km) somewhat different values would be used. If e_o, e_w, and e_f are the pressures of the aqueous vapor in centimeters at sea-level, on a mountain, and in the free air, the two latter stations being at an altitude of h meters, then

$$e_w = e_o 10^{-\frac{h}{6500}}$$

and

$$e_f = e_o 10^{-\frac{h}{6000}\left(1+\frac{h}{20000}\right)}.$$

When $h = 1730$ meters (Mount Wilson), then

$$e_w = 0.54 e_o$$

$$e_f = 0.49 e_o.$$

The more complete formula for Q is:

$$Q = 2.3 e_o \left(1 - 10^{-\frac{h}{5000}}\right).$$

Whence the total amount of precipitable water from sea-level to the limits of the atmosphere is, with Hann's constants,

$$Q_o = 2.3 e_o$$

and above the level of Mount Wilson

$$Q_w = 2.3 e_o (.45) = .45 Q_o,$$

whence

$$Q_w = 1.9 e_w.$$

[1] *Bulletin of the Mount Weather Observatory*, **4**, 121, 1911.

A summation of the data collected by Humphreys for the air above the level corresponding to that of Mount Wilson with due allowance for the increase in the vapor pressure on a mountain over what it would be in the free air at the same altitude, viz.:

$$\frac{e_w}{e_f}=\frac{0.54}{0.49}=1.10,$$

gave

$$Q_w=1.7e_w.$$

However, if the data is summed by seasons, there results:

For spring	$Q_w=1.9e_w$
For summer	$=1.6e_w$
For fall	$=1.7e_w$
For winter	$=1.6e_w$.

In the following table are given the values of K necessary to get from the wet-and-dry determinations of the vapor pressure at the surface on Mount Wilson the amount of atmospheric water-vapor as measured by the spectroscope. Five sets of data are shown: the first two including some days graded as excellent in 1910 and 1911, respectively; the third set, days when the spectroscope indicated unusual constancy in the amount of aqueous vapor; the fourth and fifth, through two notable passages over Mount Wilson of very moist periods.

The following are the means from the various sets:

First	set:	early morning,	$K_w=1.94$,	late morning,	$K_w=1.55$
Second	"	"	"	1.79	"	"	1.36
Third	"	"	"	2.82	"	"	1.52
Fourth	"	"	"	3.57	"	"	1.96
Fifth	"	"	"	1.53	"	"	1.29
All 1910:		"	"	1.94	"	"	1.55
All 1911:		"	"	2.29	"	"	1.54
All:		"	"	2.12	"	"	1.54

Omitting the two abnormally large values of K_w, 10.4 and 11.8, the mean early morning value is

$$K_w=1.8.$$

COMPARISON OF ATMOSPHERIC WATER-VAPOR DETERMINATIONS BY THE SPECTROSCOPE AND BY SURFACE HUMIDITIES

Date	Q = Water by Spectroscope When		e_w = Surface Vapor Pressure When		$Q = Ke_w$ Values of K When	
	$m = 3.0$	$m = 1.2$	$m = 3.0$	$m = 1.2$	$m = 3.0$	$m = 1.2$
First Selection, Excellent Days, 1910						
	cm	cm	cm	cm		
June 12	0.14	0.21	0.33	0.58	0.42	0.36
Aug. 13	.17	.16	.20	.41	.85	.39
Sept. 8	.26	.35	.20	.25	1.30	1.40
June 21	.26	.29	.54	.70	0.48	0.42
July 2	.29	.36	.45	.60	.64	.60
4	.33	.47	.38	.34	.87	1.38
Aug. 5	.36	.52	.30	.50	1.20	1.04
15	.38	.53	.43	.61	0.88	0.87
June 19	.43	.49	.41	.54	1.05	.91
July 5	.47	.50	.19	.40	2.47	1.25
June 6	.48	.59	.60	.71	0.80	0.83
Aug. 28	.57	.75	.34	.50	1.68	1.50
June 24	.59	.82	.70	.81	0.84	1.01
July 9	.59	.70	.35	.60	1.69	1.17
June 27	.63	.67	.53	.80	1.19	0.84
17	.69	.81	.63	.87	1.10	.93
July 7	.81	.96	.60	.95	1.35	1.01
June 16	.87	1.08	.75	.89	1.16	1.21
Aug. 17	.88	1.03	.085	.20	10.40	5.20
July 6	1.04	1.15	.28	.32	3.72	3.60
Aug. 2	1.15	1.36	.40	.62	2.88	2.20
June 10	1.44	1.99	.53	.71	2.72	2.80
Aug. 9	1.55	1.65	.75	.80	2.06	2.06
23	2.01	2.14	.71	.76	2.83	2.81
July 19	2.14	2.27	1.10	1.27	1.95	1.79
Aug. 21	2.27	2.57	0.60	0.85	3.78	2.99
Second Selection, Excellent Days, 1911						
Oct. 3	0.27	0.40	0.32	0.55	0.84	0.73
Aug. 11	.31	.36	.38	.57	.82	.63
Oct. 10	.25	.28	.14	.36	1.79	.78
Aug. 1	.36	.48	.49	.62	0.74	.77
13	.39	.44	.43	.50	.91	.88
6	.39	.48	.75	1.00	.52	.48
29	.80	.81	.31	0.58	2.58	1.40
Sept. 14	.82	.81	.62	.63	1.32	1.29
July 6	.99	1.10	.29	.48	3.41	2.29
Aug. 19	1.71	1.84	.45	.57	3.80	3.23
July 13	1.96	2.24	0.67	0.91	2.93	2.46

COMPARISON OF ATMOSPHERIC WATER-VAPOR DETERMINATIONS BY THE SPECTROSCOPE AND BY SURFACE HUMIDITIES—*Continued*

Date	Q=Water by Spectroscope When		e_w=Surface Vapor Pressure When		$Q=Ke_w$ Values of K When	
	$m=3.0$	$m=1.2$	$m=3.0$	$m=1.2$	$m=3.0$	$m=1.2$
Third Selection, Constant Vapor by Spectroscopy, 1911						
	cm	cm	cm	cm		
Sept. 7	0.27	0.24	0.49	0.74	0.55	0.33
July 5	.31	.34	.62	.59	.50	.58
Oct. 10	.35	.28	(See above)	(See above)	1.79	.78
Sept. 10	.46	.50	.41	.50	1.12	1.00
Oct. 25	.53	.60	.52	.60	1.02	1.00
Sept. 9	.64	.67	.37	.65	1.73	1.03
1	.69	.70	.30	.45	2.30	1.56
Aug. 29	.80	.81	(See above)	(See above)	2.58	1.40
Sept. 14	.82	.81	(See above)	(See above)	1.32	1.29
Aug. 21	1.13	1.10	.18	.37	6.28	2.97
20	1.36	1.43	0.115	0.30	11.8	4.79
Fourth Selection, Group August 11 to August 23, 1911						
Aug. 11	0.31	0.36	(See above)	(See above)	0.82	0.63
12	.20	.29	0.24	0.53	.83	.55
13	.39	.44	(See above)	(See above)	.91	.88
14	.42	.56	.44	.63	.96	.89
15	.39	.42	.22	.33	1.77	1.27
16	.51	.67	.24	.40	2.13	1.67
17	.75	.83	.29	.38	2.59	2.18
18	1.+	1.57	.34	.50	....	3.14
19	1.71	1.84	(See above)	(See above)	3.80	3.23
20	1.36	1.43	(See above)	(See above)	11.8	4.79
21	1.13	1.10	(See above)	(See above)	6.28	2.97
22	0.90	0.97	.21	.57	4.29	1.70
23	0.73	0.62	0.11	0.40	6.64	1.55
Fifth Selection, Group September 7 to September 18, 1911						
Sept. 7	0.27	0.24	(See above)	(See above)	0.55	0.33
8	.12	.21	0.29	0.42	.41	.50
9	.64	.67	(See above)	(See above)	1.73	1.03
10	.46	.50	(See above)	(See above)	1.12	1.00
11	1.41	1.56	.39	.54	3.62	2.89
12	1.34	1.58	.52	.56?	2.58	2.82
13	1.10	1.27	.61	.65	1.80	1.95
14	0.81	0.81	(See above)	(See above)	1.32	1.29
15	.53	.69	.59	.76	0.90	0.91
16	.28	.35	.22	.43	1.27	.81
17	.51	.44	.26	.49	1.96	.90
18	0.35	0.50	0.32	0.50	1.09	1.00

However, means from figures having such a wide range, 0.33 to 11.8, have very little significance and are of very little service for the determination of water-vapor for any single day. It is perhaps interesting to note that this last mean value, $K_w = 1.8$, lies just between the values of Hann and Humphreys, 1.9 and 1.7.

The best determinations of aqueous vapor by the spectroscope are probably those made nearer noon (smaller air masses) since they fall on the more accurately calibrated part of the curve connecting the transmissibility with the corresponding amount of water-vapor. On the other hand, the best determinations of K, which involves e_w, the surface humidity, are those of the early morning (large air masses), since the humidity at the earth's surface increases very rapidly toward noon. This increase is not nearly so marked away from the surface, although often indicated to some extent in the spectroscopic determinations as shown in some of the plots of Fig. 3. This greater increase in humidity at the surface over that in the free air is shown in the smaller values of K_w for the nearer-noon determinations.

From a consideration of the wide range of the values of K_w, 0.33 to 11.8, and the fact that sometimes the spectroscope shows a great amount of moisture in the free air when the surface humidity is very small, as for instance on August 20, 1911, it seems as if no other conclusion could be drawn than that any formula for determining the amount of atmospheric water-vapor from observed surface humidities is absolutely unsafe at least at Mount Wilson. Indeed it seems as if one ought to expect nothing else; for in the higher air the moisture in clear weather must be more or less conditioned by the quarter whence the wind comes, whereas near the surface the ground conditions and the surface convection currents will affect it.

A word or two as to the situation of Mount Wilson may be pertinent. The mountain rises fairly steeply from a more or less sandy plain near sea-level at the south to an altitude of about a mile (1.7 km); its surface is rocky, generally dry, with some few pines, stunted live-oaks, and low-lying shrubs. To the north and east rise somewhat higher, more or less bare, rocky mountains, yet farther north and east are extended desert regions; to the south-

east and southwest are low hills, then the Pacific Ocean some fifty miles away. During the months of these observations, there is very little rain, in some years none. During the night or the early morning a fog generally comes in over the valley to the south, at times high enough to cover the mountain. The pleasant-weather wind, when there is any, since calm conditions are very common, is generally westerly in the early morning; a southerly, more or less vapor-laden breeze is apt to set in toward ten o'clock to which is probably due the sudden increase then of the humidity near the surface and to some extent above.

SUMMARY

The quantity of precipitable water existing in the form of vapor between the top of Mount Wilson and the outer limits of our atmosphere during fair weather from June to November 1910, and 1911, has been determined by the spectrobolometric method described in detail in the *Astrophysical Journal*, **35**, 149, 1912.

The average quantity present was 0.69 cm and the range from 0.2 cm to about 2.8 cm of precipitable water. The difference in monthly means would be small but for a few exceptionally moist days in August; almost the dryest day indeed for 1910 was August 13 (0.17 cm) and the dryest for 1911, September 12 (0.12 cm).

A gradual but generally slow increase in atmospheric water-vapor often takes place during the observations which extend from about 7 A.M. to 10 A.M. This averages 0.12 cm. For about 40 per cent of the days this increase is less than 0.1 cm.

These spectrobolometric results were then used in a study of the formula of Hann which, with a coefficient determined from balloon and kite observations, has been in use for connecting surface humidities with the quantity of aqueous vapor in the atmosphere. This coefficient was redetermined by means of the data above discussed. The general mean for the coefficients (1.8) agrees closely with that derived by Hann (1.9) or from Humphrey's data (1.7). The range of values is, however, so great (from 0.33 to 11.80) that we must regard the formula, though applicable for mean conditions, as of no value for individual days.

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THE PLANE GRATING FOR STELLAR SPECTROSCOPY

By J. S. PLASKETT

At the meeting of the committee of the Astronomical and Astrophysical Society of America on Co-operation in Radial Velocity Determinations at Mt. Wilson in 1910, the question of increasing the efficiency of the modern stellar spectrograph was discussed and various suggestions were offered. The writer, with the consent of Dr. King, director of the Dominion Observatory, decided to test a plane grating as the dispersion piece of a stellar spectrograph. Some earlier experiments on the use of gratings in stellar spectroscopy were made by Poor and Mitchell,[1] by Wadsworth,[2] and by others but without very encouraging results. The difficulty was probably due to the loss of light entailed by its distribution over several spectra and can be overcome by obtaining a grating giving a strong concentration in one order. Gratings have been ruled by Rowland giving a very strong first-order spectrum, and both Michelson and Ames considered that it should be possible to rule gratings giving a large proportion, as much as 75 per cent of the incident light, into one order. Even if this efficiency was not reached, grating spectra should compare favorably with those produced by three-prism dispersion especially toward the violet, where the dense flint glass used in most prism trains is strongly absorbing.

Consequently a plane grating to give the strongest possible first-order spectrum was ordered through the J. A. Brashear Co., in October 1910, was ruled by Dr. J. A. Anderson of Johns Hopkins University, and received in January 1912. The grating is a 5-inch plane with ruled surface 7.4×9.4 cm ($2\frac{7}{8} \times 3\frac{3}{4}$ inches), ruling 15,000 to the inch. The total number of lines is 55,875, which will be the resolving power in the first order if the whole aperture is used. It was estimated by Dr. Anderson to diffract about 50 per cent of the incident light into one first order, but, as will be seen later, this seems to be an overestimate.[3]

[1] *Astrophysical Journal*, **7**, 157, 1898.

[2] *Ibid.*, **7**, 198, 1898.

[3] See note at end.

Considerable thought was given to the optical design of the spectrograph, and three methods of producing a spectrum were combined in the one instrument. In the first of these, the usual method, in which a parallel pencil from a doublet collimator objective of 57 mm (2.25 in.) aperture is diffracted back, making an angle of about 30° with the initial direction, is employed, the spectrum being formed by a triplet camera objective of 63.4 mm (2.5 in.) aperture and 507 mm (20 in.) focus. In the second method the autocollimating or Littrow principle is used, the combined collimator and camera objective being a triplet of 63.4 mm (2.5 in.) aperture and 951 mm (37.5 in.) focus. The spectrum is formed in the plane of, and as close as possible to, one end of the slit. The same principle is used in the third method, the grating being replaced by a half-prism of 0.102 glass having angles of 31°.5, 58°.5, and 90°, and silvered on the side opposite the 58°.5 angle. The light is refracted into the prism on the hypotenuse and, when at minimum deviation, is incident normally on the silvered side and returned along its original path, except for the slight inclination necessary to bring it on the plate. The use of the half-prism for radial velocity work was proposed by Professor Campbell at the meeting above referred to, and I understand a stellar spectrograph has been constructed at the Lick Observatory from his designs which gives very promising results. Nevertheless, as no change was needed in the grating spectrograph except the substitution of the half-prism for the grating, it was thought worth while to make tests of this type.

The linear dispersions of the three forms are 33.0 Å, 17.5 Å, and 17.5 Å per millimeter at H_γ. These values are almost identical with those given by spectrograph I (33.4 Å) and spectrograph III S (17.5 Å), one- and three-prism spectrographs of the Dominion Observatory, thus enabling accurate comparisons of relative intensities to be easily made.

The mechanical design of the spectrograph follows the supported box form, first introduced by Campbell at the Lick Observatory, of which successful examples besides those at Mount Hamilton and in Chile are the Mellon spectrograph at Allegheny and the single-prism spectrographs at Ottawa and Ann Arbor. The box is

made of brass plates firmly screwed together at the angles and thoroughly braced internally. Owing to its relative compactness as compared with the Ottawa one prism, it was not thought necessary to introduce a third counterbalancing support as in the latter instrument, but the box is held flexibly and yet firmly in the braced T iron frame by two supports so placed as to reduce flexure to a minimum. The objectives, which define beautifully, and the reflecting slit were made by the J. A. Brashear Co., but all other parts of the instrument were constructed in the observatory workshop.

Preliminary tests and adjustments made in the laboratory, using the carbon arc as the light-source, showed that the field of the spectrum was practically flat over the 4 degrees included on the plate and that the definition of all three forms was excellent.

The method adopted for obtaining the comparative intensities of prismatic and grating spectra was to make exposures successively on the same celestial objects, both sun and stars being used. Five spectra, side by side on the same plate, were made of the object by each instrument, the exposure times in every case being proportional to the numbers 1, 1.5, 2, 3, 4. For example, on *Procyon*, 5 exposures were made with III S, 5 with the Littrow grating, 5 with the Littrow half-prism, and then 5 with III S, all three instruments having the same dispersion. A similar test was carried through with the first form of the grating spectrograph and the one-prism instrument, both of the same dispersion, and repeated for other stars and for the sun. As the linear dispersions were the same, the spectra of the same width, the observing conditions fairly constant, the exposure times the same, and the plates developed together for the same time, the intensity of the resulting negatives gives a direct comparison of the intensity of the spectra. As nearly equal intensities on the plates can be compared, little photographic error is likely to occur. The results of these comparisons are given in the subjoined table.

The most striking feature in the appearance of the grating as compared with the prismatic spectra—and this is also evident from the table—is the remarkable uniformity in intensity between H_β and λ 3850. This uniformity is perhaps the most useful property

RELATIVE INTENSITIES OF SPECTRA

Wave-Length	Sun			Procyon				Rigel				Mean (Stars)			
	G.	3 P.	½ P.	G.	3 P.	½ P.	1 P.	G.	3 P.	½ P.	1 P.	G.	3 P.	½ P.	1 P.
H_β	...	2.0	3.0	0.6	2.0	4.0	5.0	0.7	2.0	3.5	5.0	0.7	2.0	3.7	5.0
4800	0.9	3.2	4.0	1.0	3.0	5.5	6.5	1.0	5.0	5.0	6.0	1.0	4.0	5.2	6.2
4700	1.3	4.5	4.5	1.3	2.5	5.5	6.5	1.2	4.2	5.0	6.0	1.2	3.3	5.3	6.3
4600	1.5	5.2	4.5	1.3	2.0	5.0	6.0	1.2	3.0	5.0	5.6	1.3	2.5	5.0	5.8
4500	1.3	4.5	4.0	1.2	1.8	4.0	5.0	1.2	1.9	3.8	5.0	1.2	1.8	3.9	5.0
4400	1.1	3.0	3.5	1.1	1.4	3.0	3.9	1.1	1.5	2.8	4.3	1.1	1.5	2.9	4.1
H_γ	1.0	2.3	3.0	1.0	1.3	2.5	3.3	1.0	1.4	2.3	3.5	1.0	1.3	2.4	3.4
4300	1.0	2.0	2.8	1.0	1.1	2.5	3.0	1.0	1.1	2.3	3.0	1.0	1.1	2.4	3.0
4200	1.1	1.2	2.6	1.0	0.7	2.3	2.5	1.0	0.8	2.0	2.4	1.0	0.8	2.2	2.5
4150	1.1	0.7	2.0	1.1	0.3	2.2	2.2	1.0	0.3	1.8	2.0	1.0	0.3	2.0	2.1
H_δ	1.1	0.5	1.8	1.1	0.1	2.0	2.0	1.0	0.1	1.6	1.8	1.1	0.1	1.8	1.9
4050	1.0	0.2	1.6	1.1	...	1.7	1.7	1.0	...	1.4	1.5	1.0	...	1.5	1.6
4000	1.0	...	1.3	1.0	...	1.4	1.3	1.0	...	1.2	1.2	1.0	...	1.3	1.3
H	1.0	...	1.0	1.0	...	1.0	1.0	1.0	...	1.0	1.0	1.0	...	1.0	1.0
K	0.9	...	0.7	1.0	...	0.8	0.8	1.0	...	0.8	0.8	1.0	...	0.8	0.8
3900	0.8	...	0.2	0.9	...	0.5	0.6	0.9	...	0.4	0.4	0.9	...	0.4	0.5
3850	0.3	...	...	0.6	...	0.1	0.2	0.8	...	0.2	0.2	0.7	...	0.1	0.2
3800	...	...	...	0.2	...	...	...	0.6	...	...	...	0.4	...	...	...
3750	...	...	...	...	...	...	...	0.3	...	...	...	0.2	...	...	...

of the grating spectrograph. The contrast between grating and prism in this respect is very striking, as prismatic spectra are over ten times, grating spectra only one and a third times, as intense at λ 4700 as at λ 3900. This difference is due in the main to two causes: first, the increased dispersion toward the violet and diminished toward the red of prismatic spectra (dispersion at K one and a half times, at H_β two-thirds, that at H_γ), while diffraction spectra are nearly normal; and second, the strong absorption of the prism glass for the shorter wave-lengths. Calculations from Vogel's constants for 0.102 glass show that through 5 cm of this glass, about the mean length of path through the single and the half-prism, 33 per cent is transmitted at the K line as compared with 71 per cent at H_γ and 85 per cent at H_β. The effect of this absorption is strikingly shown in the table where the relative intensity of three-prism as compared with single- and half-prism spectra toward the violet is given.

Discussing first the relative intensity of three-prism and grating spectra, we find the former has the advantage from H_β to about λ 4300, while from λ 4200 down grating spectra are decidedly superior, three-prism spectra disappearing below H_δ. If a spectrum in which the region from λ 4300 to the ultra-violet is required, only the grating could be used, while from H_β to H_γ the prisms would have the advantage. In other words for early-type stars use the grating, for solar type, three-prism dispersion.

Comparing next grating with single- and half-prism spectra we find the advantage lies decidedly with the latter above the H and K lines, but if the K line is required, as is the case in many early-type stars, it can be obtained with the grating in the same time as with the one-prism spectrograph without making the lines between H_β and H_γ immeasurable by overexposure.

If now the prismatic spectra are intercompared, the superiority of one- over three-prism spectra is markedly shown. The former gives nearly three times the intensity above λ 4200 and a much greater ratio below, a difference of more than a magnitude in the stars within reach of the telescope. It must not be forgotten, however, that this difference is partially offset by the threefold greater resolving power of three prisms, although in photographic

spectra their high resolution cannot be effectively employed and it is of no value in early-type stars.

A final interesting comparison is that between the one-prism and the half-prism spectra. The former gives spectra about 20 per cent more intense than the latter, a result to be expected when the loss at the silvered reflecting surface is taken into account and when the larger aperture of the half-prism (63.4 mm as compared with 51 mm) and the consequent greater length of optical path are considered. It is evident that more intense spectra would be secured by using the regular one-prism instrument rather than the half-prism, making the camera the same length as collimator. The further advantage of narrower lines for the same slit-width would be obtained by increasing the length of collimator, camera remaining the same. The advantages of the half-prism instrument are its much simpler and more compact and self-contained mechanical form, avoiding some of the flexure and temperature difficulties occurring with the extended one-prism spectrograph.

In conclusion, it may be said that although the spectra obtained from the grating are disappointingly weak and show that the proportion of the incident light diffracted into the spectrum used is nearer 30 than the 50 per cent estimated by Anderson[1] or the 75 per cent considered possible, yet even under this handicap it can be used to advantage when the K line is required and if spectra of uniform intensity or of uniform dispersion are needed. It would also be useful in the red end where prismatic spectra are so unduly compressed. If a grating giving twice the intensity could be obtained it would be superior even to single-prism dispersion for most work.

The relative flexure of prism and grating spectrograph should also be considered. It is well known that a small change in the position of a prism when at minimum deviation does not displace the spectrum, while the angular movement of a diffracted pencil will be twice that of the grating. Tests of the single-prism spectro-

[1] I have learned since the above was written that Dr. Anderson's estimate referred not to the incident light but to the percentage returned by the speculum metal surface. As the reflectivity of speculum metal is about 65 per cent the two estimates are in good agreement.

graph showed very small flexures of the order of 2 or 3 km per second. A similar test of the half-prism spectrograph showed maximum flexure of about 7 km and of the grating spectrograph of about 20 km per second. In most exposures the displacement caused by the change of position in hour-angle will not much exceed one-tenth of these amounts, and it is evident that, with proper distribution of the comparison exposures, there should be no appreciable effect on the velocity measures. Hence the question of flexure need introduce no serious difficulties in the use of a grating spectrograph.

I have much pleasure in acknowledging the interest of the Director in this work and his willingness to supply the apparatus required.

DOMINION OBSERVATORY
OTTAWA
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THE RELATION BETWEEN BLACK-BODY AND TRUE TEMPERATURES FOR TUNGSTEN, TANTALUM, MOLYBDENUM, AND CARBON, AND THE TEMPERATURE VARIATION OF THEIR REFLECTING POWER

By C. E. MENDENHALL and W. E. FORSYTHE

The increasing use of various electrically heated metallic filaments in a variety of physical experiments, together with the difficulty of determining the true temperature of such filaments, suggested the desirability of securing data which might be useful in determining the true temperature of the radiating surface from the more readily observed optical black-body temperature. Furthermore, this question is intimately connected with that of the variability or constancy of the optical reflecting power of metals, and the observations up to the present time have supported the surprising generalization that the reflecting power of metals for visible wavelengths was sensibly independent of temperature changes.

Accordingly, with these two points in view, the observations mentioned in the following pages have been made from time to time during the past two years. In the meantime Pirani and Meyer[1] have published data on some of the same metals, covering somewhat the same temperature range; but our results do not agree with theirs where they overlap, while our method seems essentially simpler and more direct.

Method.—For a discussion of the validity and accuracy of the method used by us, reference must be made to a previous paper;[2] the essential feature is the production of black-body radiation by forming a narrow V-shaped radiator either by folding a flat strip parallel to its length, or by combining two flat strips touching at one edge. Observations with a calibrated optical pyrometer taken in the mouth of the V will then give the true temperature of the inside

[1] *Verhandlungen der deutschen physikalischen Gesellschaft*, **14**, No. 5, p. 213; No. 13, p. 681.

[2] Mendenhall, *Astrophysical Journal*, **33**, 91, 1911.

surface, while observations on the flat side will give the "black-body" temperature of the outside surface. In the paper referred to it was shown that for metal strips of the dimensions used, the *real* difference of temperature between the outer and inner surfaces might be expected to be so small that it could be neglected; further evidence on this point will be brought forward in the present paper.

As further evidence of the reliability and accuracy of the method, the following observations of the true (T) and black-body (S) temperatures of the melting-point of palladium may be quoted:

	T	S
	1549° C.	1378° C.
	1548	1387
	1546	1384
Mean	1548—	1385 (weighted)

For the melting-point of palladium Day and Sossman have directly determined $T=1549°$ C., while Waidner and Burgess observed $S=1387°$ C. Other schemes of more or less closely realizing black-body radiation have been used by Pirani,[1] but none, it seems to us, as simple and at the same time as certain to realize the desired conditions, as that here used.

Temperature scale.—Our basis throughout is the high temperature scale adopted by the Bureau of Standards according to which the melting-points of gold and palladium are 1063° C. and 1549° C. respectively, while in determining the radiation scale in terms of which all our true temperatures have been expressed, Wien's law in the form—

$$\log E_\lambda = K - \frac{1}{T} \cdot \frac{c_2}{\lambda}$$

with the value $c_2=14.500$, has been used.

Since the wave-length used in observing was $0.658\,\mu$, the maximum value of the product λT is 2170, well within the limit $\lambda T=3000$ for which Wien's law is supposed to be essentially valid. The validity of Wien's law at extreme high temperatures should be subjected to further study, and such study is in fact now under way in this laboratory. As to the errors involved in applying Wien's

[1] *Verhandlungen der deutschen physikalischen Gesellschaft*, **8**, 427, 1912.

law with the only approximately monochromatic light transmitted by our red-glass screens, we have also tested this[1] up to 2500° C. and have found no systematic error due to this cause.

Pyrometers.—These were of the Holborn-Kurlbaum form already described,[1] though not of the spectroscopic type. Instead, red glass having a maximum transmission at $\lambda = 0.658\ \mu$ was used in the eyepiece; accordingly our *black-body* temperatures apply to observations with this wave-length. The pyrometers were calibrated from the melting-point of palladium directly determined with a platinum-wound black-body furnace.

Preparation of the strips.—The strips were about 3 cm long, and from 5 to 8 mm wide along the side of the V, while the angular opening was about 10°. The metal strips varied in thickness in different cases from 0.02 to 0.04 mm. The tantalum was rolled from heavy sheet obtained from Siemens and Halske, and the molybdenum rolled from a ductile specimen kindly furnished by the General Electric Co. In each of these cases the V was formed by folding. The tungsten was of the ductile variety also furnished by Director Whitney of the Research Laboratory of the General Electric Co., ground down to the desired uniform thickness, the V being formed by two flat strips touching along one edge. We were unable to obtain carbon of the kind used in incandescent lamps, in the form of broad strips flat enough to make a satisfactory V, though the General Electric Co. very kindly made some strips for us of both metalized and untreated carbon. We were therefore forced to use a very compact fine-grained plate carbon, of which we had two varieties, one from Conradti and the other from the National Carbon Co. No difference was found between them. It was found impracticable to use carbon strips thinner than 0.08 mm, and on this account and because of the relatively low thermal conductivity of carbon, it was impossible to neglect the real temperature difference between the inner and outer surfaces of the V. The simplest way of eliminating this difference seemed to be to determine the apparent difference of temperature for a constant inside temperature, with several thicknesses of wall, and to graphi-

[1] *Physical Review*, **33**, p. 74, 1911.

cally extrapolate to zero thickness. The curves by which this was done are shown in the corner of Fig. 4, the three thicknesses being 0.08, 0.12, and 0.20 mm. In carrying out the extrapolation, consideration was given to fitting an individual curve to the group as a whole.

Condition of the surfaces.—In order to realize black-body conditions on the inside of the V it is desirable to have the side walls plain and fairly well polished. The initial surface of our metals was either that given by polished rollers or that obtained by polishing with the finest grade of emery paper. The latter treatment was also given the carbon surfaces. After a little use at high temperatures, however, the surfaces of all the materials are changed more or less by sublimation, and in the case of carbon probably also by slight graphitization. Our results are intended to apply to such *used* surfaces. In the case of carbon the effect of heating (of course *in vacuo*) is to make the surface less compact, undoubtedly permanently lowering the reflecting power. In the case of the metals, while the surface is altered considerably in appearance, especially with tungsten, this alteration seems to consist mainly in the development of *facets* which destroy the flatness of the surface, though the individual facets seem to be highly polished. These changes seem to us to be such as would alter the *specular* reflecting power, but not seriously change the emissive or absorbing power of the surfaces. We found that more consistent results were obtained if the filaments were given a preliminary heating of a minute or so, at a fairly high temperature before observations were begun.

Arrangement of apparatus.—All the filaments were heated *in vacuo*. The vacuum vessel was provided with an arrangement for taking up the expansion of the filaments, and thus preserving the shape of the V, a very important consideration. The vessel was continually exhausted by a Gaede pump, the pressure being usually a few thousandths of a millimeter, as measured on a McLeod gauge. When using tantalum it was found desirable also to heat calcium in the vacuum before heating the filament. Pyrometer observations were made through glass windows, the correction for which was carefully determined.

Errors.—1) Calibration errors. These (assuming the validity of Wien's law) we estimate to be not more than $\pm 3^\circ$ at the extreme high temperatures.

2) Correction due to glass window. This was determined for *clean* glass with a maximum uncertainty of not more than 2° at the highest temperature, but much greater errors doubtless entered with a few individual observations through failure to detect slight deposits of sublimed metal or carbon on the inside of the windows.

3) Failure to realize black-body conditions on the inside of the V, due to warping or welding together of the sides of the V, or to the opening of a crack at the back of those V's made from two pieces. No observations were taken under obviously bad conditions. These errors *always* tend to diminish the apparent difference in temperature between inside and outside of the V, hence in general the larger differences are more probably correct. In general the longer a V is used, especially at high temperatures, the more care must be taken to avoid the welding together of the sides of the V.

4) Variable conditions of outside surface of the V. We are inclined to minimize the magnitude of such uncertainties.

5) A real difference of temperature between outside and inside of wedge. Besides the evidence already referred to showing that this difference is small, we have made observations with different thicknesses of molybdenum filaments varying from 0.028 mm to 0.038 mm, without being able to detect any difference due to this cause.

6) The variation of temperature across the flat side of the V is usually small, and may be made quite negligible by properly varying the thickness of the strip from edge to center. Our observations were made on the middle of the flat side; in a few cases there was quite a considerable variation, from 25° to 50° across the face of the strips at very high temperatures.

7) Errors due to unsteady electrical and temperature conditions. The much greater consistency of the observations on molybdenum as compared with those on tantalum and tungsten is partly due to better control and partly to greater care in avoiding errors 3) and 6).

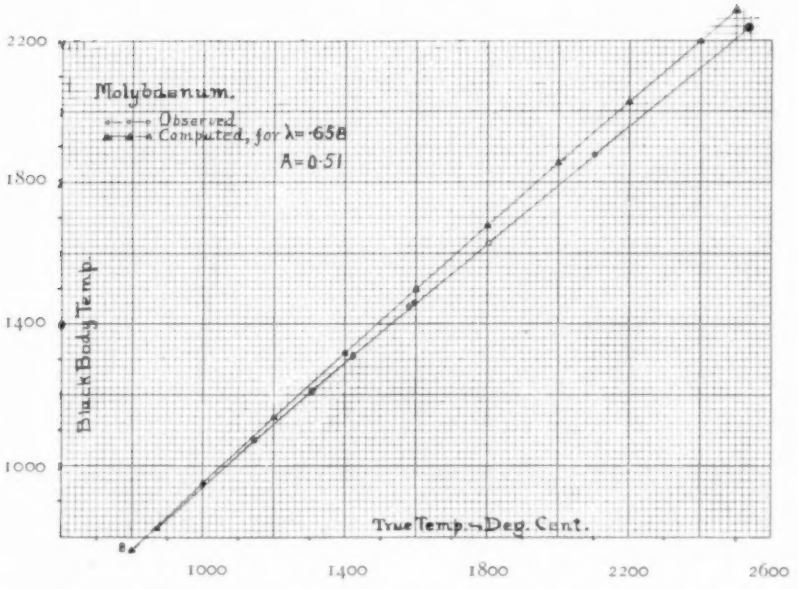

FIG. 1.—Relation between true temperature (T, abscissae) and black-body temperature (S, ordinates), for molybdenum, both observed and computed.

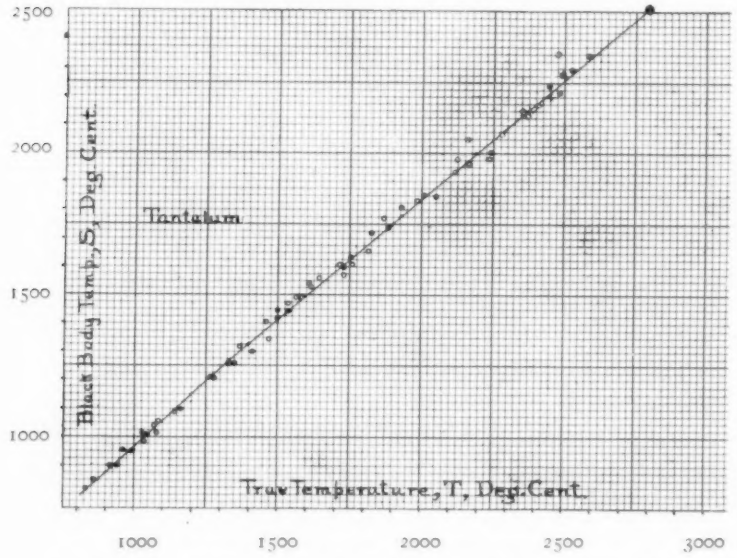

FIG. 2.—Relation between true temperature (T, abscissae) and black-body temperature (S, ordinates), for tantalum; observed values only.

Results.—The results are shown in Figs. 1–4, and the table gives the co-ordinates of a number of points on the lines, giving in each case the graphical average. Considerable weight is given to the melting-points, because they depend partly on independent data already published by one of us,[1] and because in general

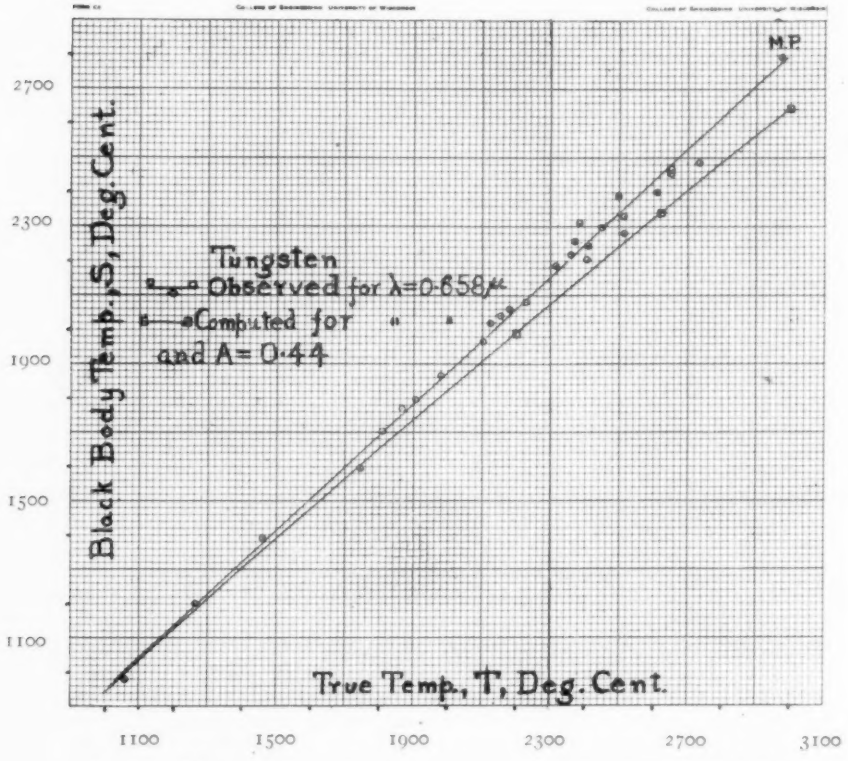

FIG. 3.—Relation between true temperature (T, abscissae) and black-body temperature (S, ordinates), for tungsten, both observed and computed.

black-body conditions were better with the fresh filaments used for melting.

In drawing the line through the observed points, some attention has been paid to the fact that the most probable error (3) tends to make $T-S$ too small. It will be noticed that a slight curvature of the T, S-curve is always indicated, especially for the lower range of

[1] *Astrophysical Journal*, **34**, 353, 1911.

temperatures, though in the case of molybdenum the relation is linear from 1500° up, and for tungsten a linear relation from 1000° to 3000° is all that the observations warrant.

Variation of optical reflecting power with temperature.—The equation

$$\log A = \log(1-R) = \left(\frac{1}{T}-\frac{1}{S}\right)\frac{c_2}{\lambda}\log e,$$

an immediate consequence of Wien's law first suggested by Holborn and Henning, has been used by Wartenberg, Pirani, and

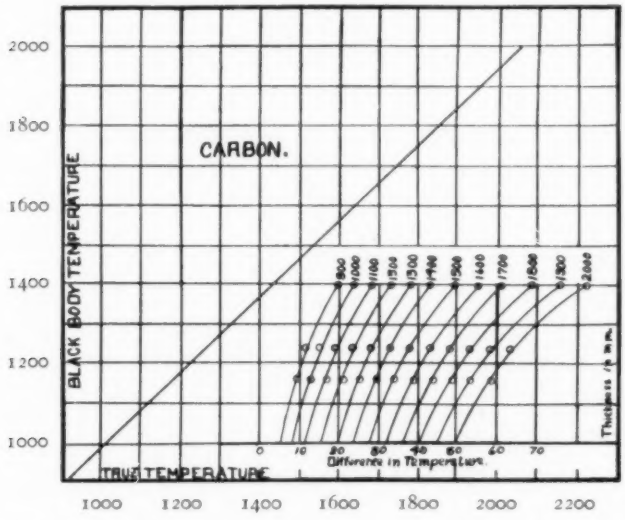

FIG. 4.—Relation between true temperature (T, abscissae) and black-body temperature (S, ordinates), for carbon, observed; curves used for determining corrections due to thickness of strip.

others to compute T from S for various metals, assuming R to be the same at high temperatures as at low. Concerning the constancy of R there is the evidence of Holborn and Henning[1] for platinum up to the melting-point; of Hagen and Rubens[2] for *Pt* and *Pt*+*Rh* up to 1450° C. (for $\lambda = 0.78\,\mu$) and the approximate figures of Wartenberg for palladium and rhodium. None of this evidence seems to us at all conclusive; and in fact Holborn and Henning's *computed* value of the melting-point of platinum, when compared with the value at present accepted, really indicates an increasing

[1] *Berl. Akad. Ber.* (1905), p. 311. [2] *Preuss. Akad. Ber.*, **23**, 467, 1910.

rather than a constant reflecting power. Our curves seem to be quite inconsistent with the assumption of a constant reflecting power, and to point definitely to a change in the optical reflecting power with temperature, an *increase* for molybdenum, tantalum, and carbon, and a *decrease* for tungsten. The case is especially

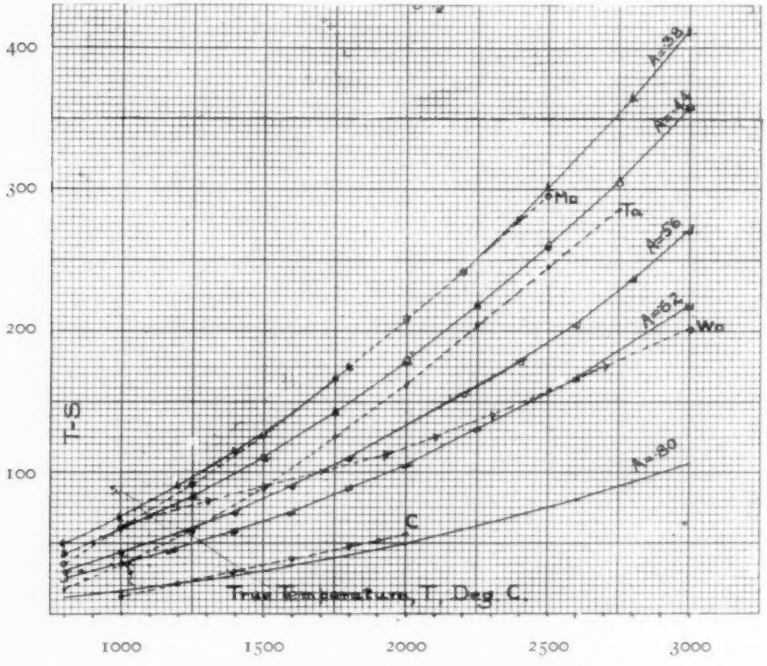

FIG. 5.—Broken curves, observed values of $T-S$ and T for the several metals; solid curves, values of $T-S$ and T computed for the several reflecting powers noted, by the equation

$$\frac{1}{T}\cdot\frac{1}{S}=\frac{\lambda\cdot\log(1-R)}{C_2\log e}$$

clear for *Mo* and *Wo*—for as may be seen from Figs. 1 and 3, the T, S-curves at 800 to 1000° agree with those computed from the low-temperature reflecting power, but depart markedly from these computed curves at high temperatures. The absorbing power used for ductile tungsten at ordinary temperatures is based on the recent measurement of Littleton,[1] allowance being made for the change in λ from $0.589\,\mu$ to $0.658\,\mu$, in accordance with data

[1] *Physical Review*, **35**, 306 (1912).

quoted by Burgess.[1] While our curve indicates a change in R for tantalum, it must be said that a T, S-curve computed for $R=0.51$ comes more nearly fitting the experimental curve than will any curves, computed with R constant, for the other metals. But this value of R does not agree with Wartenberg's[2] observations at ordinary temperatures.

TABLE I

BLACK-BODY AND TRUE TEMPERATURES

BLACK-BODY TEMPERATURE	CORRESPONDING TRUE TEMPERATURE			
	Tungsten	Tantalum	Molybdenum	Carbon
800° C.	.....	....	840	....
1000	1068° C.	1035	1068	1012
1200	1273	1255	1295	1222
1400	1486	1485	1530	1430
1600	1700	1720	1770	1638
1800	1910	1955	2010	1847
2000	2126	2190	2250	2056
2200	2345	2430	2490	....
2400	2565	2665	....	....
2600	2783	....	....	....
2700	2890	....	....	....

The observations in their bearing on reflecting power are summarized in Fig. 5—from which it may be seen that the reflecting powers vary as follows:

$$Mo \begin{cases} 1000^\circ\ \text{C} \ldots\ldots 0.56 \\ 2400^\circ\ \text{C} \ldots\ldots 0.63 \end{cases}$$

$$Ta \begin{cases} 1100^\circ\ \text{C} \ldots\ldots 0.40 \\ 2600^\circ\ \text{C} \ldots\ldots 0.52 \end{cases}$$

$$Wo \begin{cases} 1100^\circ\ \text{C} \ldots\ldots 0.55 \\ 2900^\circ\ \text{C} \ldots\ldots 0.34 \end{cases}$$

$$C \begin{cases} 1000^\circ\ \text{C} \ldots\ldots 0.14 \\ 2000^\circ\ \text{C} \ldots\ldots 0.21 \end{cases}$$

While our individual observations, except in the case of molybdenum,[3] are subject to large accidental errors, the graphical average

[1] *Measurement of High Temperatures* (1912), p. 497.

[2] *Verhandlungen der deutschen physicalischen Gesellschaft*, **12**, p. 105, 1910.

[3] Most of the points plotted on the molybdenum curve are the means of several *sets* of observations taken at different times and on different strips, but the variations (with one exception) are of the order of 1° to 3°. This degree of consistency among the observations is largely due to careful control of the heating current, in such a way as to maintain S (apparent temperature outside of V) constant, while several observations of T (temperature inside of V) were made.

we consider to be fairly accurate, and on the whole to indicate very decidedly the variations in reflecting power stated above.

Summary.—Data have been given in the form of curves and tables from which the true temperature (T) of radiating surfaces of tungsten, tantalum, molybdenum, and pressed carbon may be determined from observations of the black-body temperature (S) using $\lambda = 0.658\,\mu$. From these curves it is concluded that the optical absorbing power of these substances varies with temperature instead of being constant as hitherto considered.

Department of Physics
University of Wisconsin
February 1913

ON THE PRESSURE-SHIFT OF IRON LINES

By H. G. GALE and W. S. ADAMS

In the course of an investigation of the displacements of the iron lines at a pressure of 8 atmospheres made in 1910 and 1911[1] we found that most of the lines could be classified according to the amount of their pressure-shifts into several groups. The first of these, group *a*, consists mainly of the low temperature "flame" lines. The average displacement for this group at λ 5000 is between 0.003 and 0.004 Ångström. For group *b* the displacements are large, and for groups *c* and *d* larger yet, averaging in the case of group *d* about 0.02 Ångström per atmosphere. The lines of groups *c* and *d* become very wide and diffuse under pressure, and in the case of group *d*, at least it was impossible to make more than a rough estimate of the amount of shift.

A most important addition to these groups was later made by St. John and Ware[2] who in their article on "Tertiary Standards with the Plane Grating" showed that certain lines in the iron spectrum are displaced to the violet by pressure. Their results were obtained by comparing measurements of the iron arc lines on photographs taken on Mount Wilson and in Pasadena, at a difference in altitude corresponding to a difference of about one-fifth of an atmosphere in barometric pressure. These lines were classified as group *e* and the shifts were found to be relatively large.

On account of the diffuseness of the lines of groups *c* and *d* at a pressure as high as 8 atmospheres it seemed desirable to repeat the measurements of these lines at much lower pressures, including also the lines of group *e* which are quite unmeasurable at considerable pressures.

For this purpose Mr. Swaim kindly obtained a number of photographs at pressures ranging from a partial vacuum of 5 or 10 cm

[1] *Astrophysical Journal*, **35**, 10, 1912.

[2] *Ibid.*, **36**, 14, 1912.

Wave-Length	Group	No. of Measures	Δ per Atm.	Δ 8 Atm.
4859.928	*c*	5	+0.017	+0.100
4871.512	*c*	5	+0.018	+0.080
4872.332	*c*	5	+0.017	+0.094
4878.407	*c*	5	+0.016	+0.087
4890.048	*c*	5	+0.016	+0.070
4891.683	*c*	5	+0.014	+0.052
4919.174	*c*	5	+0.016	+0.072
4920.685	*c*	5	+0.014	+0.082
4957.480	*c*	5	+0.013	+0.083
4957.785	*c*	5	+0.016	+0.086
4994.316	*a*	5	+0.001	.....
5012.252	*a*	5	+0.001	.....
5051.825	*a*	5	+0.004	.....
5065.207	*e*	4	−0.016	.....
5074.932	*e*	7	−0.007	.....
5083.518	*a*	3	+0.003	.....
5097.175	*e*	4	−0.008	.....
5110.574	*a*	6	+0.005	.....
5125.300	*d*	5	+0.026	.....
5133.870	*e*	8	−0.020	.....
5162.449	...	7	+0.060	.....
5167.678	*a*	8	+0.003	.....
5195.647	*e*	5	−0.007	.....
5227.362	*a*	10	+0.004	+0.031
5233.122	*d*	10	+0.022	+0.11
5266.738	*d*	10	+0.021	+0.13
5269.723	*a*	10	+0.004	+0.027
5340.121	*d*	8	+0.022	+0.14
5341.213	*a*	8	+0.004	+0.028
5365.069	*e*	6	−0.021	.....
5367.669	*e*	6	−0.020	.....
5370.166	*e*	6	−0.008	.....
5371.734	*a*	6	+0.004	+0.029
5373.905	*e*	4	−0.013	.....
5383.578	*e*	5	−0.013	.....
5393.375	*d*	5	+0.020	+0.14
5397.344	*a*	6	+0.005	+0.029
5404.357	*e*	5	−0.012	.....
5405.989	*a*	6	+0.004	+0.027
5411.124	*e*	6	−0.020	.....
5415.416	*e*	6	−0.020	.....
5424.290	*e*	6	−0.025	.....
5429.911	*a*	6	+0.003	+0.029
5445.259	*e*	6	−0.018	.....
5447.130	*a*	6	+0.004	+0.031
5463.174	*e*	6	−0.009	.....
5463.494	*e*	6	−0.007	.....
5466.609	...	5	+0.050	.....
5476.500	*a*	6	+0.004	+0.029
5476.778	*d*	6	+0.020	+0.11
5487.959	...	6	+0.078	.....
5497.735	*a*	6	+0.004	+0.030
5501.683	*a*	6	+0.003	+0.030
5507.000	*a*	6	+0.004	+0.031
5543.414	*e*	6	−0.012	.....
5555.122	*e*	6	−0.018	.....

Wave-Length	Group	No. of Measures	Δ per Atm.	Δ 8 Atm.
5558.209	*d*	5	+0.026	.....
5562.933	*e*	4	−0.004	.....
5563.824	*d*	5	+0.022	.....
5565.931	*e*	4	−0.009	.....
5586.991	*d*	6	+0.024	+0.12
5594.884	*e*	4	−0.018	.....
5598.524	*e*	4	−0.018	.....
5603.186	*d*	6	+0.022	+0.15
5615.877	*d*	6	+0.024	+0.13
5624.769	*d*	5	+0.024	+0.16
5659.052	*d*	6	+0.022	+0.15

to 1 or 2 atmospheres. They were taken in the second order of a 21-foot concave grating at the Ryerson Laboratory with the pressure-box which was used by us in our previous work at the Pasadena Laboratory of the Mount Wilson Observatory. The photographs were measured for the most part by Miss Lasby of the Mount Wilson computing staff.

The measures at present include about 180 lines in the region between λ 4800 and λ 5700, and will be extended both toward the red and toward the violet. A discussion of the results naturally will await the completed measures but some of the more interesting lines are given in the adjoining table. Among these is a complete list of lines in this region which show displacements toward the violet under pressure, as well as a few lines which show enormous displacements toward the red amounting to over twice that of the average for the group *d* lines. The shifts have been reduced to Ångströms per atmosphere. The last column contains the displacements found by us previously at 8 atmospheres.

These results amply confirm the violet displacements found by St. John and Ware although the numerical values are considerably smaller. The lines of group *e* are characterized by great diffuseness and widening at a pressure as low as even one atmosphere. They are, however, more nearly symmetrical than are the lines of group *d* which are always very diffuse on the red side.

A comparison of these results for a pressure of one atmosphere with our previous results for 8 atmospheres indicates that the present values are somewhat larger. In the case of the lines of group *d*, the agreement, however, is quite as good as could be

expected for lines of this character, and perhaps the same may be said of the lines in group *c*. It seems certain that the displacements of lines which belong to groups *c*, *d*, and *e* may be measured much more accurately at low pressure than at pressures of several atmospheres.

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The Summer Quarter

of

The University of Chicago

1913

PRELIMINARY LIST
OF COURSES

A Circular giving complete
information will be issued about March 1
and will be sent on request

GENERAL INFORMATION

The Organization of the University includes: the Graduate School of Arts and Literature; the Ogden (Graduate) School of Science; the Colleges (Senior and Junior) of Arts, Literature, and Science; the Divinity School, the Law School, Courses in Medicine, the College of Education, the College of Commerce and Administration.

Faculty, Endowment, and Equipment.—The faculty numbers three hundred and thirty-seven; the libraries contain 381,351 books and 195,000 pamphlets (estimated). The University owns 90 acres of land in Chicago and has 35 buildings.

Location of the University.—The University grounds lie on both sides of the Midway Plaisance between Washington and Jackson parks, six miles south of the center of Chicago. Electric cars, elevated trains, and the Illinois Central suburban service reach all railway stations.

The University Year is divided into quarters: the Autumn (October to December); the Winter (January to March); the Spring (April to the middle of June); the Summer (middle of June to August). Students are admitted at the opening of each quarter; graduation exercises are held at the close of each quarter.

Admission to Colleges and Schools.—Students must present satisfactory evidence of the completion of a four years' course in an acceptable high school or academy in order to be admitted to candidacy for the Bachelor's degrees. Graduate students must possess Bachelor's degrees from accredited colleges. Qualified students over twenty-one may be admitted as unclassified students.

The Unit of Work and of Credit is a major, i.e., a course of instruction involving four or five recitations or lecture hours per week for a full quarter, or double that number of hours for a term of six weeks. A minor is one-half a major. Normal work is three majors per quarter, or nine per year of three quarters.

Degrees.—In the Graduate Schools are conferred the degrees of Doctor of Philosophy and Master of Arts, of Science, and of Philosophy; in the Colleges, the degrees of Bachelor of Arts, of Science, of Philosophy; in the Divinity School, the degrees of Bachelor of Divinity, Master of Arts, and Doctor of Philosophy; in the Law School, the degrees of Doctor of Laws and Bachelor of Laws; in the College of Education, the degrees of Bachelor of Arts, Philosophy, or Science, in Education.

Tuition, Fees, etc.—The regular fee for three major courses in Arts, Literature, and Science, and in the College of Education is $40 per quarter. All students pay once a matriculation fee of $5. In Law and Medicine, the fees are $50 and $60.

Cost of Living.—In University dormitories rooms rent from $25 to $75 per quarter. The charge for table-board in the women's halls is $4.50 per week. At Hutchinson Hall (à la carte service) board costs from $3.50 per week upward. Board and lodging may be had at the same or even lower rates outside the University.

Fellowships, Scholarships, Student Service, etc.—By virtue of endowments and special appropriations, fellowships and honor scholarships and service afford stipends or free tuition to a number of able and deserving students. Further information is contained in a circular entitled *Assistance to Students*, which will be sent upon request.

THE SUMMER QUARTER

These Announcements are provisional and incomplete. A detailed circular will be issued about March 1.

The Calendar for 1913.—The First Term begins Monday, June 16, and closes Wednesday, July 23; the Second Term begins Thursday, July 24, and ends Friday, August 29, the Autumn Convocation being held on the afternoon of that day.

A Quarter of Regular Work for Credit.—In the personnel of the teaching staff, in scope and methods of instruction, and in credit-value the work of the Summer Quarter ranks with that of the other quarters of the academic year.

Precaution about Gaining Admission.—Undergraduate students should make sure that they are eligible for admission before they leave home for Chicago. Persons thus failing to make arrangements in advance may be rejected or directed to the University High School. Graduate students should inquire in advance as to their eligibility for registration in the Graduate Schools. Application in writing should be made to the University Examiners.

Limitation of Work, etc.—The student is limited to three minor courses for each term, or to three major courses for both terms. In special cases permission may be obtained from the deans to pursue an additional course, for which in the case of undergraduate students, a supplementary fee must be paid. Graduate and Law students are given larger privileges, and students in the College of Education may add one of the arts without additional fee.

Graduate Study.—College professors and school teachers, clergymen, and members of other professions, holding Bachelor's degrees from accepted colleges, may avail themselves of the facilities of the University to pursue advanced studies under the guidance of research professors in all the chief departments of investigation.

Biblical and Theological Study.—The Divinity School offers to professors of theology, to theological students, to ministers, to religious workers, and to others interested in biblical and theological study, introductory and advanced courses in all its departments. See p. 11.

Professional Courses in Law.—Students beginning the study of law, those in the midst of their professional studies at Chicago or elsewhere, and practicing lawyers are offered work of a thorough and systematic character. See p. 14.

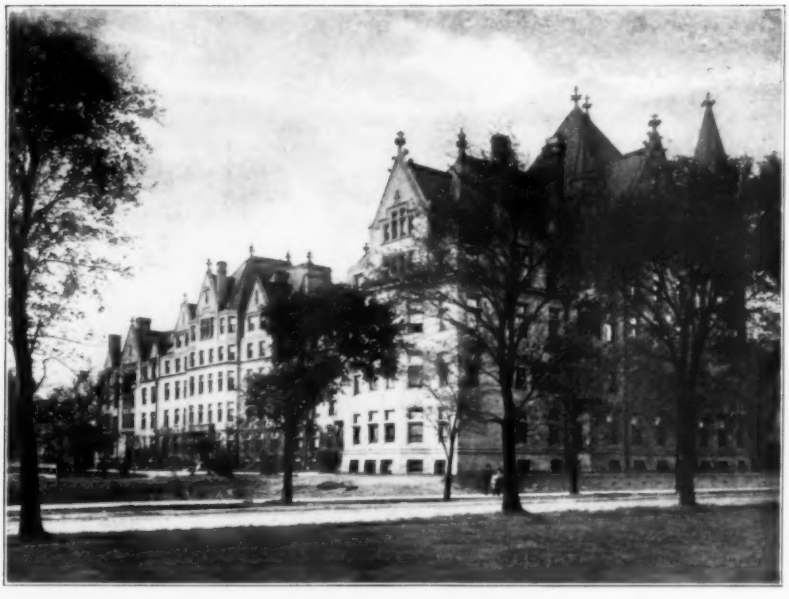
Courses in Medicine.—College seniors planning to study medicine, students in medical schools, and practitioners will find the summer course in medicine admirably adapted to their needs. The Summer Quarter is of especial value to students who need to review and to make up work. See p. 16.

Educational Principles and Methods.—The courses of all departments have a bearing upon the work of teaching, but the courses of the College of Education are peculiarly adapted to the professional needs of teachers, both in primary and secondary schools. The work in the various shops affords unusually complete instruction in the industrial arts and crafts. See. p. 11.

Public Lectures.—A series of public lectures, concerts, and other forms of entertainment is scheduled throughout the Summer Quarter, and affords opportunity to students to hear speakers of eminence and artists of distinction.

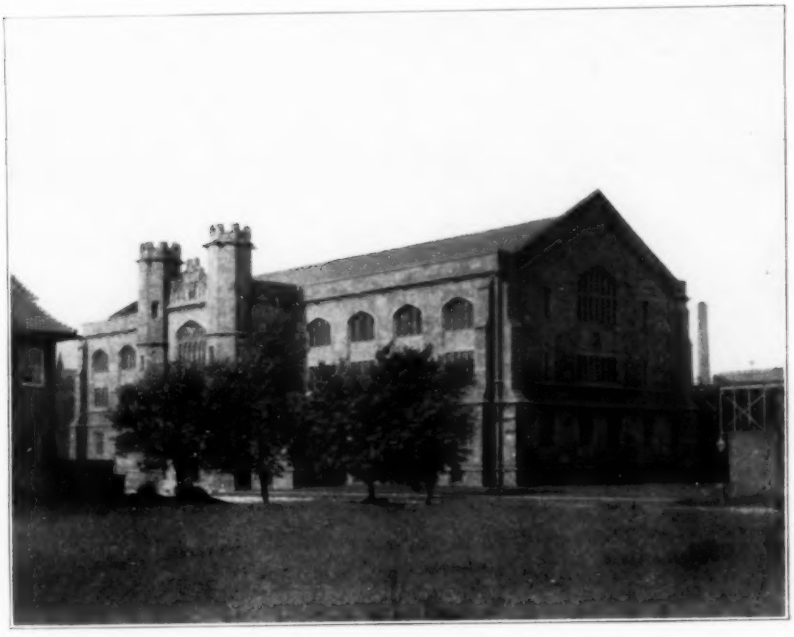
Chicago in Summer.—An agreeable summer temperature, spacious parks, notable libraries and museums, great industrial plants, typical foreign colonies, a number of Settlements, and other significant social institutions make Chicago a peculiarly appropriate center for study and investigation.

COBB HALL AND MEN'S DORMITORIES



WOMEN'S HALLS

HUTCHINSON COMMONS, MITCHELL TOWER, AND THE REYNOLDS CLUB



BARTLETT GYMNASIUM

Excursion Parties.—It has been customary, especially in the South, to organize special excursion parties for the journey to Chicago. The University will be glad to put inquirers into communication with the organizers of such parties.

ARTS, LITERATURE, AND SCIENCE

NOTE.—The following condensed paragraphs contain hardly more than titles of courses. No systematic attempt is made to indicate (*a*) the character of the courses; (*b*) to what types of students they are open; (*c*) what prerequisites are demanded; or (*d*) at what hours the classes meet. All details are given in the complete announcements, which will be mailed promptly to all who apply to the UNIVERSITY OF CHICAGO, CHICAGO, ILLINOIS.

Philosophy, Psychology, and Education.—Courses will be offered in Metaphysics, in Ethics, and in the History of Philosophy; in Elementary and Advanced Psychology, in Genetic and Experimental Psychology, in Educational Psychology, in the History of Education, in School Organization and Administration, in the Formation of the Curriculum, in the Relation of the Arts to the Course of Study, in Industrial Education, in Child-Study, and in the Pedagogy of the various subjects of the school course.

Political Economy, Political Science, History, Sociology and Anthropology, and Household Administration.—Courses will be offered in the Principles of Political Economy, in Transportation, in Taxation, in Public Finance, in Statistics, in Values, in Distribution of Wealth, and in Money; in Constitutional Law; in Ancient History, in Mediaeval and Modern History [Church and State], in English History, Political and Industrial, in American Constitutional History, and in various periods of Political and Industrial History, also Teacher's Course in American History; in Archaeology and Anthropology, in the Fundamental Ideas of Sociology, in the Growth of Sociological Method, in Rural Sociology, in Social Technology; in the Chemistry of Food Preparations, in Home Economics, in House Sanitation, and in the Legal and Economic Aspects of Household Administration.

Semitics and Biblical Greek.—Courses will be offered in the Interpretation of the Old Testament, in Elementary and Advanced Hebrew, in Assyrian and Egyptian Languages, and in History; and in New Testament History.

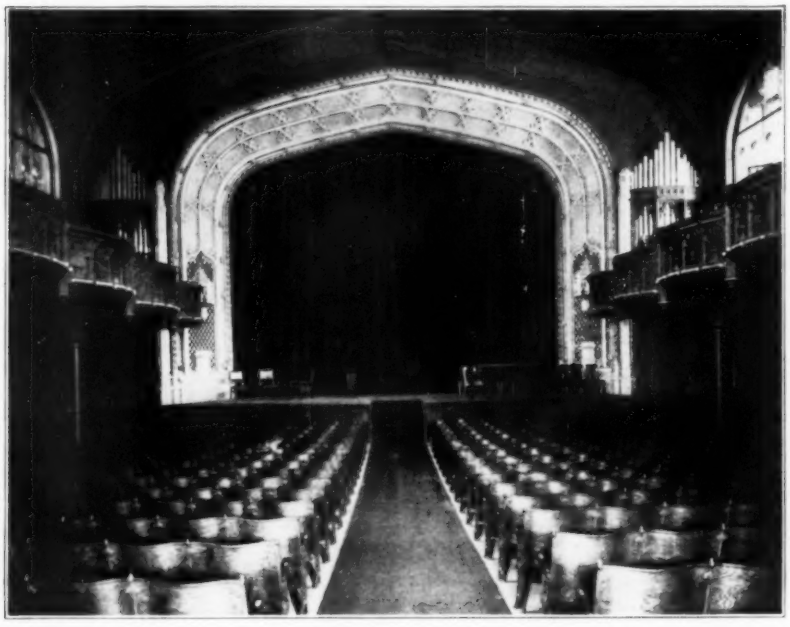
Comparative Religion.—Courses will be offered in the Outline History of Religion and in the Philosophy of Religion.

History of Art, Sanskrit, Greek, and Latin.—Courses will be offered in Prehistoric Art in Greece, in Greek Architecture, in Roman Sculpture, in Roman Coins, in an Introduction to the Study of Art, and in Flemish and Dutch Painting; in Elementary Sanskrit, in the Study of the Veda, in Hindu Religion, in Indo-European Comparative Philology, in an Introduction to the Study of Language, and in Outlines of Latin Historical Grammar; in Beginning Greek, in Anabasis, in Homer, Iliad and Odyssey, in Plato's Apology, in an Introduction to Greek Tragedy, in Aristotle's Poetics, in Lyric Poetry, in Isocrates, and in the Public Orations of Demosthenes; in Cicero, De Senectute, De finibus, Academica, and De Natura deorum, in Terence, the Phormio, in Livy, in Horace, Odes and Epodes, in Catullus, in Juvenal, in Virgil's Aeneid, with especial reference to the technique, in Ovid, Metamorphoses, in Horace, Satires, in Roman Private Life, in Colloquial Latin, and in the Training of Teachers, first-year work in the Training of Teachers, course in Caesar, and in the Comparative Syntax of the Greek and Latin Verb.

Modern Languages.—Courses will be offered in Old English, in Middle English, in various periods of English Literature, and in English Composition; in Elementary and Intermediate French, in Old French Literature, in various

periods of later French Literature, in Phonetics, in French Grammar, in Spanish, and in Italian; in Elementary and Intermediate German, in the History of German Literature, in Recent German Literature and Drama, in Gothic, and in Middle High German; in Dante in English, and in the Short Story in various literatures.

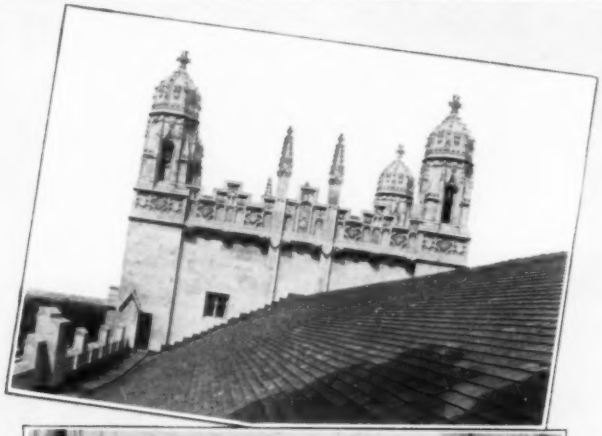
Mathematics, Astronomy, Physics, and Chemistry.—Courses will be offered in Trigonometry, College Algebra, Plane Analytic Geometry, Graphic Analysis, Differential and Integral Calculus, in Advanced Calculus, in Theory of Functions, also Synoptic Course in Higher Mathematics; Definite Integrals, Differential

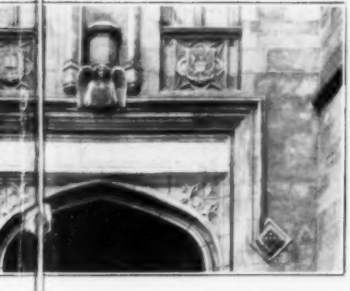


AUDITORIUM OF LEON MANDEL ASSEMBLY HALL

Geometry, Theory of Physical Units, Theory of Numbers, Vector Analysis, General Analysis, and Reading and Research in Pure and Applied Mathematics; Descriptive Astronomy, Introduction to Celestial Mechanics, Analytic Mechanics, Research work at the Yerkes Observatory; Theoretical Optics, Light Waves and Their Uses, Advanced Spectroscopy, Relativity, Electron Theory, Research, work, Graduate laboratory work, Electric Waves, Mechanics, Molecular Physics and Heat, Electricity, Sound, and Light, and Physical Manipulation, two Courses for Teachers; Elementary General Chemistry; General Inorganic Chemistry, Elementary and Advanced Qualitative and Quantitative Analysis, Special Methods of Analysis, Elementary Organic Chemistry, Advanced Organic Preparations, Advanced Inorganic Preparations, Elementary and Advanced Physical Chemistry, Advanced Physico-chemical Measurements, Research in Organic, Inorganic, and Physical Chemistry.

WILLIAM RAINEY HARPER



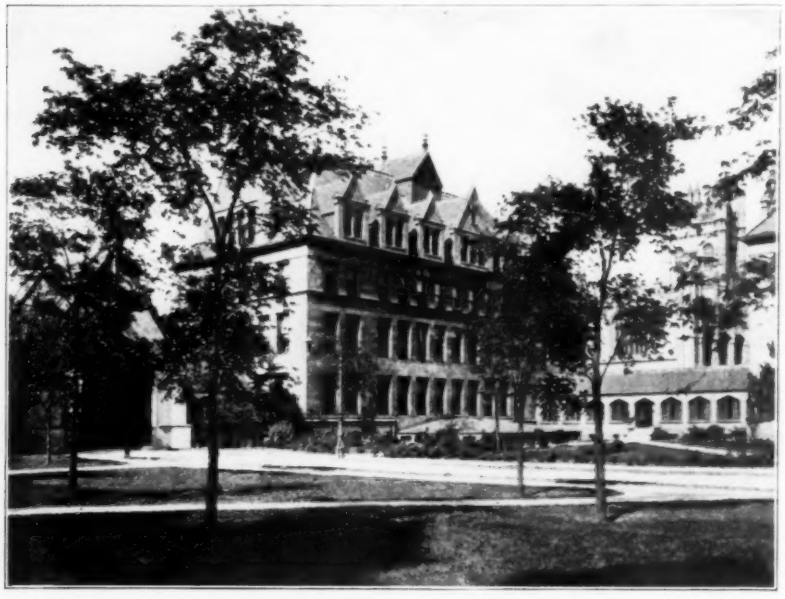


HARPER MEMORIAL LIBRARY

Geology and Geography.—Courses will be offered in Physiography, in General Geology, in Economic Geology, in Elementary Mineralogy and Petrology, and several Field Courses for students of different stages of advancement; in the Conservation of Natural Resources, in the Geography of Europe, in Geographic Influences on American History, in Advanced and Elementary Commercial Geography, and perhaps in Anthropogeography.

The Biological Departments.—At the Marine Biological Laboratory, Woods Hole, Mass., courses in Zoölogy, Embryology, Botany, Physiological Chemistry, General and Comparative Physiology, and Biological Research, will be offered, for which credit is allowed in the University.

At the University of Chicago courses will be offered in Elementary Zoölogy, in Elementary Economic Field Zoölogy, in Experimental Behavior and Ecology,



HULL BIOLOGICAL LABORATORY AND MITCHELL TOWER

in Animal Geography, in Vertebrate and Invertebrate Zoölogy, in Genetics and Experimental Evolution, in Microscopical Technique, and advanced work in Zoölogy, including research, and in Embryology; in Introductory Anatomy; in Topographical Anatomy, Histology, in Anatomy of the Ear, Nose, and Throat, and in advanced research work; in Introductory Physiology, in Physiology of Digestion, Metabolism, Absorption, etc., in Physiology of Mammals, in Physiology of the Organs of Internal Secretion, in Research, and review courses in Physiology; in Teaching Botany in the High School, in Research in Morphology, in Special Morphology of Gymnosperms, in Research in Ecology, in Elementary Ecology, in Research in Taxonomy, in Classification of Vascular Plants, in General Morphology of Thallophytes, in Methods in Plant Histology, in Growth and Movement, in Research in Plant Physiology, in Elementary Plant Pathology, in Elementary Botany, and in Ecological Anatomy; in General Pathology and

Pathological Histology, in the Pathogenic Bacteria, in Sanitary Water Analysis, and in Research in Pathology and in Bacteriology.

Public Speaking.—Courses will be offered in Elementary and Advanced work in Public Speaking, with particular stress on the Vocal Interpretation of Literature, Oral Composition, and the pedagogy of both subjects as applied to High-School and College curricula.

THE SCHOOL OF EDUCATION

The School of Education of the University of Chicago consists of four divisions: (1) The Graduate Department of Education; (2) The College of Education; (3) The University High School; (4) The University Elementary School.

The Graduate Department of Education gives advanced courses in principles and theory of education, educational psychology, history of education, and social and administrative aspects of education. The Master's degree and the degree of Doctor of Philosophy are conferred.

The College of Education is a College of the University, with all the University privileges, and in addition provides the professional training of elementary and secondary school teachers and supervisors. It offers undergraduate courses in professional subjects and in the methods of arranging and presenting the various subject-matters which are taken up in the elementary and secondary schools. Certain of these courses can be completed in two years and lead to certificates; other courses cover a period of four years and lead to a Bachelor's degree.

The University High School with the fully equipped shops of the Manual Training School is in session during the Summer Quarter. Opportunity is offered to take beginning courses in Latin and German and to review courses in Mathematics, English, and History. The regular shopwork supplemented by discussions of methods is open to teachers pursuing these courses.

The University Elementary School.—Only the kindergarten department of the Elementary School is in session during the first term of the Summer Quarter. This offers an opportunity for observation.

COURSE OF INSTRUCTION IN THE GRADUATE DEPARTMENT AND IN THE COLLEGE

Courses in the Pedagogy of History and Literature in the Grades, in Home Economics, in English, in Mathematics, Physics, Geography, the Biological Sciences, School Library Economics; also in Oral Reading and in Hygiene and Physical Education, in Kindergarten Theory and Practice, in Children's Reading, in Aesthetic and Industrial Arts, in Household Art, and Review Courses in various subjects in the High School, will be offered, in addition to those named on p. 3.

THE DIVINITY SCHOOL

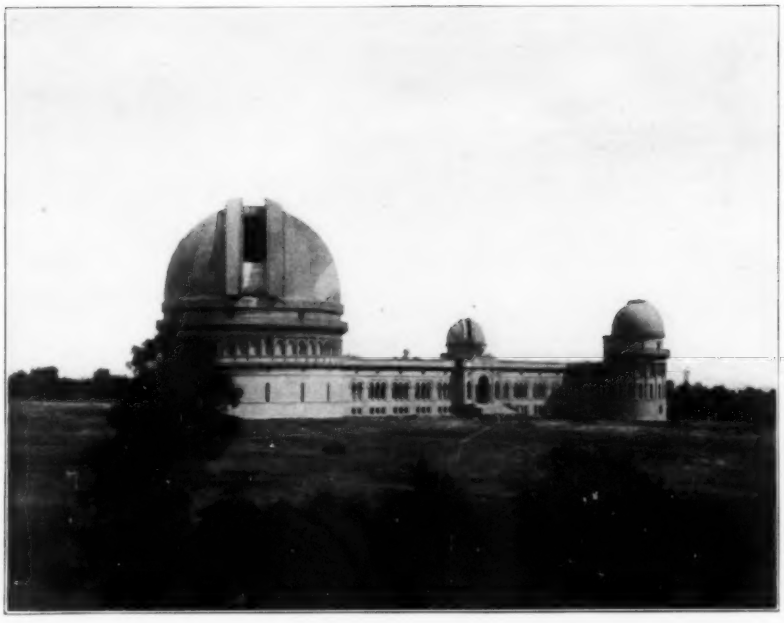
Admission.—The Divinity School is open to students of all denominations. The instruction is intended for ministers, missionaries, theological students, Christian teachers, and others intending to take up some form of religious work.

The English Theological Seminary is intended for those without college degrees. It is in session only during the Summer Quarter.

The Graduate Divinity School is designed primarily for college graduates. Pastors, theological teachers, students in other seminaries, and candidates for the ministry with requisite training are admitted in the Summer Quarter.

RYERSON PHYSICAL LABORATORY

HULL BOTANICAL LABORATORY



YERKES OBSERVATORY

THE UNIVERSITY PRESS

Expenses.—No tuition fee is charged in the Summer Quarter. Incidental and library fees to the amount of $5 are charged, and matriculants pay the usual $5 fee. Dormitory rooms cost $8.75 to $12.75 per quarter; table-board about $3 per week in clubs or families.

In addition to the courses referred to on p. 3 there will be offered courses in Old and New Testament, in Biblical Theology, in Systematic Theology, in Church History, in Homiletics, in Religious Education, in Ecclesiastical Sociology, in Music, and in Public Speaking. Courses will be offered also in the Disciples' Divinity House.

THE LAW SCHOOL

Scope of Work.—The work of the Law School is intended for students whose education and maturity have fitted them to pursue serious professional study. The method of instruction employed—the study and discussion of cases—is designed to give an effective knowledge of legal principles, and to develop the power of independent legal reasoning. The three-year course of study offered constitutes a thorough preparation for the practice of law in any English-speaking jurisdiction. By means of the quarter system students may be graduated in two and one-fourth calendar years.

The Summer Quarter.—Regular courses of instruction counting toward a degree are continued through the Summer Quarter. Either advanced or beginning students may enter the school in the summer, and continue in the Autumn or in the next Summer Quarter. The courses are so arranged that students may take one, two, or three quarters in succession in the summer only, before continuing in a following Autumn Quarter. The summer work offers particular advantages to teachers, to students who wish to do extra work, and to practitioners who desire to study special subjects.

Building and Library.—The Law School occupies a building erected especially for it within the University quadrangles, and is equipped with a law library containing about 38,000 volumes.

Admission Requirements and Degrees.—Only college graduates or students who have had college work equivalent to three years in the University of Chicago are admitted as regular students, candidates for the degree of Doctor of Law (J.D.). The University permits one year of law to be counted as the fourth year of college work, making it possible to obtain both degrees in six years.

Students over twenty-one years old who have completed at least a four-year high-school course may be admitted as candidates for the degree of Bachelor of Laws (LL.B.), but must maintain a standing 10 per cent above the passing mark. In rare instances students over twenty-one who cannot meet these requirements will be admitted as unclassified, not candidates for a degree.

Fees.—A matriculation fee of $5 is required of every student entering for the first time. The tuition fee is $50 a quarter ($25 a term).

All correspondence concerning the Law School should be addressed to JAMES P. HALL, Dean of the University of Chicago Law School, Chicago, Ill.

Courses Offered.—During the Summer, 1913, the Law School will offer courses in: Contracts, Criminal Law, Title to Real Estate, Damages, Constitutional Law, Mortgages, Wills, Sales, and Trusts.

THE SCHOOL OF EDUCATION

COURSES IN MEDICINE

First Two Years of the Medical Course.—Courses in Medicine constituting the first two years of the four-year course in medicine of Rush Medical College are given at the University of Chicago. For the majority of students taking up medical work for the first time, it is of decided advantage to enter with the Summer or the Autumn Quarter. For the student who is lacking in any of the admission courses, or who seeks advanced standing, it is of especial advantage to enter for the Summer Quarter.

Requirements for Admission.—The requirements for admission comprise (*a*) fifteen units of high-school work, demanded for admission to the Junior Colleges of the University, and (*b*) two years of college work, which must have included at least four majors of college chemistry, including both inorganic and organic, and qualitative analysis (in addition to the year of high-school chemistry), one major of college biology with laboratory work, two majors of college physics, and a reading knowledge of German or French. Admission to advanced standing is granted students from other recognized institutions under suitable restrictions. *The inclusive fee in the Medical Courses is $60 per quarter.*

Courses for Practitioners.—All the courses offered are open to practitioners of medicine, who may matriculate as unclassified or as graduate students. No student may register for a particular course unless he has had the prerequisite work. Attention is called to the fact that certain courses of special value to practitioners are given in the summer. Practitioners taking this work are free to attend the clinics at Rush Medical College without charge.

Courses in Medicine will be found listed on p. 10.

VARIOUS UNIVERSITY ACTIVITIES

UNIVERSITY PUBLIC LECTURES

By means of public lectures and entertainments of an educational character the University presents many opportunities for culture and instruction apart from the work of the laboratory and the classroom. The lectures are delivered by eminent scholars. Concerts or recitals will be given Tuesday evenings and popular lectures Friday evenings throughout the Summer Quarter.

CORRESPONDENCE-STUDY DEPARTMENT

The teachers and students who for any reason cannot come into residence during the summer or other quarters may study under the direct personal guidance of University instructors who conduct by correspondence more than three hundred and twenty-five of the classroom courses. The tuition fee is $16 for one major, $30 for two, and $40 for three. Work may begin at any time.

Bulletin of Recent Publications of *The University of Chicago Press*

1913

AGENTS

THE BAKER & TAYLOR COMPANY, New York

THE CAMBRIDGE UNIVERSITY PRESS, London and Edinburgh

TH. STAUFFER, Leipzig

THE MARUZEN-KABUSHIKI-KAISHA, Tokyo, Osaka, and Kyoto

Bulletin of Recent Publications of *The University of Chicago Press*

The Courts, the Constitution, and Parties. Studies in Constitutional History and Politics. By Andrew C. McLaughlin, Professor of History in the University of Chicago.

308 pages, 12mo, cloth; $1.50, postpaid $1.63

A volume of peculiar interest at this time, when the courts and political parties are subject to general criticism. The discussion is especially significant as coming from a lifelong student of constitutional questions, whose work at the University of Michigan, the Carnegie Institution of Washington, and as head of the Department of History in the University of Chicago, is so widely known. The point of view is historical. Though the articles are scientific they are directed to the reader who is interested in public affairs rather than to the professional student. The work consists of five papers, the first of which discusses the power of a court to declare a law unconstitutional. Two of the papers deal with the growth and essential character of political parties, and are followed by one on the history of differing theories of the federal Union. The work concludes with a discussion of the written constitution in some of its historical aspects, taking up the origin of these documents and the problems of their maintenance and interpretation in the development of the modern popular state.

The Mechanistic Conception of Life. Biological Essays by Jacques Loeb, Head of the Department of Experimental Biology, Rockefeller Institute for Medical Research.

238 pages, 12mo, cloth; $1.50, postpaid $1.65

The achievements of Professor Jacques Loeb in the field of experimental biology have made him so widely known as to insure any book of his a large circle of readers. His experimental work at the universities of Chicago and California, as well as in his present position, gives this volume an especial significance.

In his latest work, *The Mechanistic Conception of Life*, Professor Loeb presents many of the current problems in biology,

and discusses the question whether the phenomena of life can be explained by physical and chemical laws. He finds it possible to control by physical or chemical means not merely the processes of reproduction, but also the conduct of animals with reference to environment.

The New York Medical Journal. The profession, as well as everyone interested in biology, will thank the author and the publishers for collecting these essays and placing them before the reading public.

The Chicago Tribune. It is refreshing to contemplate the wonderful exactitude, clearness, honesty, and unanswerable logic of Dr. Loeb.

Heredity and Eugenics. By John M. Coulter, William E. Castle, Edward M. East, William L. Tower, and Charles B. Davenport.

312 pages, 8vo, cloth; $2.50, postpaid $2.70

Leading investigators, representing the University of Chicago, Harvard University, and the Carnegie Institution of Washington, have contributed to this work, in which great care has been taken by each contributor to make clear to the general reader the present position of evolution, experimental results in heredity in connection with both plants and animals, the enormous value of the practical application of these laws in breeding, and human eugenics. The volume is profusely illustrated.

The Nation, New York. "Heredity and Eugenics" may be heartily recommended to readers seeking, as beginners, to get in touch with the discussion of these subjects. . . . . In most of the lectures there is an admirable reserve, not to say skepticism, in the treatment of large questions which the public is often misled to regard as already and finally settled.

Railway Economics. A Collective Catalogue of Books in Fourteen American Libraries. Prepared by the Bureau of Railway Economics, Washington, D.C.

450 pages, 8vo, cloth; $3.00, postpaid $3.28

Much of the literature relating to railways is widely scattered. The student of railway transportation finds it impossible to secure access to any all-embracing sources of information in any one of even the largest general libraries.

In the present work the Bureau of Railway Economics has undertaken to list the works relating to the economics of railway transportation that are catalogued in thirteen of the principal libraries of this country, together with those in its own collection.

The volume can fairly lay claim to being a representative bibliography in the field of railway economics.

It is confidently believed that the work will prove valuable to all interested in the literature of railway transportation, and particularly to the economist and practical railroad man.

The Evening Post, New York. Of all these invaluable aids to the student which the librarians of the country are producing, this is the most exhaustive and workmanlike of any that has been issued in the economic field.

American Permian Vertebrates. By Samuel Wendell Williston, Professor of Paleontology in the University of Chicago.

152 pages, 39 plates, 8vo, cloth; $2.50, postpaid $2.68

This work comprises a series of monographic studies with briefer notes and descriptions of new or little-known amphibians and reptiles from the Permian deposits of Texas and New Mexico. The material upon which these studies are based was for the most part collected during recent years by field parties from the University of Chicago. The book is offered as a contribution to knowledge on the subject of ancient reptiles and amphibians, with such summaries and definitions—based chiefly on American forms—as our present knowledge permits. The work is illustrated by the author.

Athenaeum. The paleontologist will welcome the work as a solid contribution to our knowledge of a fauna which is of exceptional interest to the student of evolution, inasmuch as it includes forms that help to bridge over some of the differences between reptiles and amphibians.

Morphology of Gymnosperms. By John M. Coulter, Professor of Botany, and Charles J. Chamberlain, Associate Professor of Botany, in the University of Chicago.

470 pages, 462 illustrations, 8vo, cloth; $4.00, postpaid $4.22

This work is a revised and enlarged edition of the book brought out by Professors Coulter and Chamberlain in 1901. Each of the seven great groups is here presented in detail, and a final chapter discusses the problem of phylogeny and points out the evolutionary tendencies. The extinct groups, notably the primitive "seed-ferns," are now included for the first time; and vascular anatomy is fully recognized as a morphological subject of first importance. The entire presentation is thoroughly and system-

atically organized and arranged with a view to the greatest possible clearness. The illustrations are numerous and in large part original.

Nature. The book is an invaluable record, admirably illustrated, of our present knowledge of the older type of seed-plants.

The Historicity of Jesus. A criticism of the contention that Jesus never lived, a statement of the evidence for his existence, an estimate of his relation to Christianity. By Shirley Jackson Case, Assistant Professor of New Testament Interpretation in the University of Chicago.

360 pages, 12mo, cloth; $1.50, postpaid $1.62

Did Jesus ever live, or is he a mythical personage like the deities of Greece and Rome? is to many people a somewhat startling question. But in recent years his actual existence has been vigorously questioned, and the subject is being given wide notice and discussion. The negative opinion has found supporters in America, England, Holland, France, and Germany. To present a complete and unprejudiced statement of the evidence for Jesus' actual existence is the aim of the author of *The Historicity of Jesus.*

The Nation, New York. It is creditable to American scholarship that the first survey of the entire debate should have been made by a representative of an American divinity school, and that the treatment of the question is adequate and fair in the presentation of the arguments on both sides, and marked by discernment both of the underlying principles and the consequences involved for the religious life.

Sociological Study of the Bible, Showing the Development of the Idea of God in Relation to History. By Louis Wallis, formerly Instructor in Sociology in the Ohio State University.

One volume, bound in cloth; $1.50, postpaid $1.68

This book is written on the basis of the modern scientific interpretation of the Bible; but it approaches Bible-study from a new point of view, using the sociological method of research. The ancient Hebrew nation is treated as a social group originating at the point of contact between Amorite city-states and Israelite clans from the Arabian desert. The great struggle within the nation was primarily between the legal usages of the constituent races. This conflict found expression very slowly in terms of

antagonism between the gods of the Israelites and the Amorites. Mr. Wallis' papers on the subject have been appearing for some years in the *American Journal of Sociology;* but they are entirely recast and revised for book publication.

The Dial. A significant and closely reasoned work.

The Scotsman. Whether or not one agrees with Mr. Wallis, the originality and freshness of his views and the marked ability with which they are propounded cannot be denied.

The Minister and the Boy. By Allan Hoben, Associate Professor of Homiletics in the Divinity School of the University of Chicago.

Illustrated, 180 pages, 12mo, cloth; $1.00, postpaid $1.10

From the first chapter on "The Call of Boyhood," through one on "The Approach to Boyhood," the author leads us by suggestion and informing principle to realize the remarkable opportunity afforded by the raw material "boy," on which the minister may work. Later chapters on play and vocational choice show how to train the boy for citizenship, how responsive he is to the right sort of impetus, and how his religious life may indirectly, and even unconsciously, be stimulated by the proper appeal to his manly instincts, while furnishing him with a normal outlet for his natural enthusiasm. The book is practical throughout, and each chapter is filled with concrete suggestions which are vitalized by the author's actual experience as a basis.

Mr. Hoben's book is not only enlightening and entertaining, but is wonderfully practical. It should be in the hands of every probation officer, pastor, teacher, and parent.—JUDGE BEN B. LINDSEY.

Scientific Management in the Churches. By Shailer Mathews, Dean of the Divinity School in the University of Chicago.

66 pages, 12mo, cloth; 50 cents, postpaid 55 cents

Why not apply "scientific management" to the varied activities of the church? is the question asked by Dr. Shailer Mathews in his book. The crying need for it is almost startlingly portrayed, and the broad lines of the plan—the adaptation of "scientific management" to an institution such as the church—are inspiring in their suggestiveness.

The book is of the utmost value to all who belong to the active organization in their church—or who are, in the language of the author, "spiritual workmen."

The Independent. A small volume containing matter of large practical value.

The Continent. Dean Mathews' treatment of the subject is practical, and his suggestions are exceedingly useful.

The Ethics of the Old Testament. By Hinckley G. Mitchell, Professor of Hebrew and Old Testament Exegesis in Tufts College.

420 pages, 12mo, cloth; $2.00, postpaid $2.15

The aim of the author is to present a faithful and, as nearly as possible within the limits of a manual, a comprehensive view of the development of ethical ideas among the Hebrew nation. To this end he takes the books, or parts of books, of the Old Testament in the order of their origin, and discusses their teaching, whether direct or indirect, on the duties that men owe to themselves, their families, and the larger world of which they are a part. This is the first volume to be issued in the series of "Handbooks of Ethics and Religion" edited by Shailer Mathews.

Congregationalist and Christian World. It goes far to popularize the results of modern Biblical scholarship, and in general is within the comprehension of ordinary Bible students.

Old Testament Story. Teacher's Manual and Pupil's Notebook. By Charles H. Corbett.

Manual, $1.00, postpaid $1.09; Notebook, 50 cents, postpaid 59 cents

This latest addition to the Constructive Bible Studies, covering the period from Moses to Solomon, is designed for teachers of pupils from ten to twelve years of age corresponding to grades five and six of the public school. The pupil's equipment consists of a loose-leaf notebook containing a page for each lesson. It includes pictures, maps, outlines, paper models, and an occasional written lesson, thereby providing considerable opportunity for handwork.

The Churchman, New York. Teachers will find much that is helpful in Mr. Corbett's manual.

Unity, Chicago. The unique and really valuable part of the Corbett work is his Pupil's Notebook that accompanies it.

American Poems. Selected and Edited with Illustrative and Explanatory Notes and a Bibliography. By Walter C. Bronson, Litt.D., Professor of English Literature in Brown University.

680 pages, 12mo, cloth; $1.50, postpaid $1.68

The book offers a most carefully chosen and well-balanced presentation of the poetic works of Americans, covering the entire period of our history. For the teacher as well as the student the value of the work is greatly enhanced by the comprehensive Notes, Bibliography, and Indices. It is believed that

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This series of four volumes is intended primarily to afford college classes and general readers a convenient, inexpensive, and scholarly collection of the most important English poetry.

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The questions upon the following comedies are being issued in pamphlet form: A Midsummer-Night's Dream, Much Ado about Nothing, I Henry IV, II Henry IV, The Merchant of Venice, As You Like It, Twelfth Night, The Tempest.

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Questions on Shakespeare Part I, Introduction; 75 cents, postpaid 81 cents.

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152 pages, 16mo, cloth; 75 cents, postpaid 82 cents

The constantly growing use of this book offers convincing testimony to its value as a practical guide for teachers, supervisors, and parents. It presents in outline a working theory of elementary English, with selected references to the recent literature of the subject. In this way the book is especially adapted to individual study and to group discussions in normal schools, teachers' reading circles, teachers' institutes, and parents' associations. The book contains also a suggestive course of study in composition, grammar, word-study, reading, and literature. Definite standards of attainment in these subjects are indicated for each year. Graded lists of material include stories for reading and for telling, poems for study and memorizing, supplementary reading-books classified by subjects, and selected literary studies for higher grades. The Appendix contains a

list of books to be read to the children, a list of verse collections, and a list of prose collections. The author's long connection with the Department of English in the Chicago Teachers College qualifies him to speak with authority on the subject. The book has been endorsed by the *Course of Study*, the official publication of the Chicago public schools.

Educational Review. A good book. . . . . The thoughtful and studious teacher of elementary English will find it full of helpful suggestions and advice.

Agricultural Education in the Public Schools. By Benjamin M. Davis, Professor of Agricultural Education in Miami University.

170 pages, 8vo, cloth; $1.00, postpaid $1.12

In this book Professor Benjamin M. Davis has attacked the problem of the co-ordination of all the agencies now at work on the problem of agricultural education. He has performed a service which will be appreciated by all who have any large knowledge of the problem and of the difficulties which the movement encounters. He has made an effort to canvass the whole field and to give a detailed exposition of the forces employed in building up a rational course of agricultural education. He has presented more fully than anyone else the materials which define the problem and which make it possible for the teacher to meet it intelligently. The annotated bibliography at the end of the book will do much to make the best material available for anyone desiring to get hold of this material through independent study. The book serves, therefore, as a general introduction to the study of agricultural education.

Nature. Professor Davis may be congratulated on a most valuable and thoughtful expert contribution to the literature of his subject.

A Descriptive Catalogue of Manuscripts in the Libraries of the University of Chicago. Prepared by Edgar Johnson Goodspeed, Associate Professor of Biblical and Patristic Greek and Assistant Director of Haskell Oriental Museum.

140 pages, 8vo, cloth; $1.00, postpaid $1.11

This catalogue containing the description of ninety-nine manuscripts in the possession of the University of Chicago was published in connection with the dedication of the Harper

Memorial Library, June 11, 1912. At that time the manuscripts were transferred to permanent quarters in the Manuscript Room of the new Library. Not all the manuscripts of the University are here included, the Greek papyri in Haskell Oriental Museum and the East Indian and other oriental manuscripts being reserved for separate treatment. Most of the manuscripts described in the catalogue came to the University with the Berlin Collection in 1891. The languages of the manuscripts include Latin, Greek, Italian, Spanish, French, German, English, Dutch, Icelandic, Hebrew, and Arabic.

Outlines of Economics, Developed in a Series of Problems. By Members of the Department of Political Economy of the University of Chicago.

160 pages, interleaved, 12mo, cloth; $1.00, postpaid $1.13

This book is an attempt on the part of its authors to make some advances in the direction of improving the current methods of teaching the elementary course in economics. The ideals which have shaped the character of the book are: (1) A belief that the elementary course in economics offers exceptional opportunities for training in thinking and reasoning—a sort of training the importance of which can hardly be exaggerated. The inductive-problem method here used is believed to be the one best adapted to accomplish this end. (2) A desire to connect the theoretical principles of economics with the actual facts and with problems of the business world, and to induce the student to apply his knowledge of that world to the subject of study.

The result is a careful, analytical syllabus of the subjects usually covered in the introductory course, accompanied by some 1,200 questions and problems, designed: (*a*) to afford set problems for written work; (*b*) to guide the student in his reading, while fostering independent thinking; (*c*) to give direction to classroom discussion. It is expected that the *Outlines* will be used in connection with some textbook.

Nation. In their *Outlines of Economics, Developed in a Series of Problems*, three members of the Department of Political Economy in the University of Chicago have performed with remarkable thoroughness and grasp a task of great difficulty. The book consists in the main of sets of searching questions, dealing successively with every phase of the great subject, the order being determined by the attempt of the

authors "not only to link economic theory with descriptive material, but in a measure to build the theory up out of the familiar events of economic life"; an attempt in which, we believe, they have succeeded as completely as the case admits.

Pragmatism and Its Critics. By Addison Webster Moore, Professor of Philosophy in the University of Chicago.

296 pages, 12mo, cloth; $1.25, postpaid $1.36

The general discussion of the philosophical movement known as "pragmatism" has awakened so spirited a controversy that the present volume is especially timely and significant. Professor Moore lays stress on three phases of the question: (1) the historical background of the movement; (2) its relation to the conception of evolution; (3) the social character of pragmatic doctrines. *Pragmatism and Its Critics* is a good example of the modern type of philosophical exposition. It is in a free, conversational style, is profound without being difficult, and simple without sacrificing accuracy.

Philosophical Review. No student is likely to read these chapters without receiving valuable help. The last chapter of this group, "How Ideas Work," is especially noteworthy as containing one of the most attractive and forcible presentations of the pragmatist theory of truth and error.

The Theology of Schleiermacher. By George Cross, Professor of Christian Theology in the Newton Theological Institution.

356 pages, 12mo, cloth; $1.50, postpaid $1.65

Professor Cross's book attempts to introduce the English-speaking student to Schleiermacher himself. It consists principally of a condensed "thought-translation" of his greatest work, *The Christian Faith.* The exposition is introduced by the interesting story of Schleiermacher's life, with emphasis on his religious experience. This is accompanied by a luminous account of the changes in Protestantism that necessitated a reconstruction of its doctrines. The work closes with a critical estimate of Schleiermacher's contribution to the solution of present religious problems, which in the judgment of scholars will stand as an extremely valuable portion of the book. Taken together, the translation, the analysis, and the critical estimate reveal Schleiermacher as a pioneer in modern religious thought.

The Christian World, London. This work is as timely as it is able. It is remarkable that, considering the enormous influence of Schleiermacher on modern theology, the English-speaking world has hitherto had such meager opportunity of studying the man and his teaching.

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The annual reports (each issued in two parts) contain important papers and discussions on pedagogical subjects, concerning which detailed information will be furnished on request. The Yearbooks for 1895–99, for 1902–6, and for 1907–11 have been bound together, the price of each volume being $5.00, postpaid $5.30.

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Six volumes of Papers and Proceedings have been issued. Price per volume, $1.50, postage extra.

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This is a series of educational papers recently begun under the supervision of the editors of the *School Review*. The first number, *Research within the Field of Education, Its Organization and Encouragement*, will be sent postpaid for 53 cents; the second number, embracing articles on various educational subjects, for 56 cents. Both have been prepared by the Society of College Teachers of Education.

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Bibliography of Social Science. Edited by Dr. Hermann Beck, Berlin, and Dr. Charles Kinzbrunner, London, in co-operation with the Department of Political Economy in the University of Chicago. Published monthly. Annual subscription, $6.00. We are exclusive agents for the United States and Canada. Full information on combination rates with other journals on request. Complete sets of back numbers can be furnished at special rates.

Arrangements have been completed by which the American agency for the following journals of the Cambridge University Press will be in the hands of the University of Chicago Press, beginning January 1, 1913:

Biometrika

Parasitology

Journal of Genetics

The Journal of Hygiene

The Modern Language Review

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The Journal of Agricultural Science

Correspondence regarding details of service on these journals is invited.

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BOOKS

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254 pages, demi folio, half morocco; $37.50, postpaid $38.36

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Vols. I and II, each 294 pages, crown quarto, half vellum; two vols. $12.50, postpaid $13.25

This work contains an account of the development in Eastern and Western Europe of Post-Roman architecture from the fourth to the twelfth century. It attempts not merely to describe the architecture, but to explain it by the social and political history of the time. The description of the churches of Constantinople and Salonica, which have a special interest at this time, is followed by an account of Italo-Byzantine work at Ravenna and in the Exarchate, and of the Romanesque styles of Germany, France, and England. Most of the illustrations are from drawings by either the author or his son, and add great artistic value to the volumes.

The Duab of Turkestan. A Physiographic Sketch and Account of Some Travels. By W. Rickmer Rickmers. With 207 Maps, Diagrams, and Other Illustrations.

580 pages, royal 8vo, cloth; $9.00, postpaid $9.44

A record of exploration of a little-known region, combined with some elementary physiography. The book discusses the various geographical elements in the natural organic system of the Duab of Turkestan (or Land between the two Rivers) between the Oxus and the Jaxartes, the information being strung on the thread of an interesting story of travel and mountain exploration. The author was at great pains to obtain typical views of physical features such as mountains, valleys, and glaciers, and also of vegetation, village life, and architecture; and there are many diagrams for a clearer understanding of the text.

The book is especially suitable for colleges, libraries, and schools, and for all students or teachers of physical geography and natural science.

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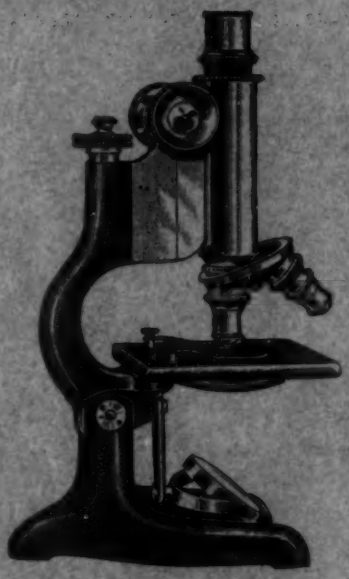

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